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30 November 2015

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Subject: Submission of "Draft Addendum #2 Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona"

The Air Force is pleased to submit the attached document, Remedial Design and Remedial Action Work Plan (RD/RAWP) for Operable Unit 2, in draft format for your review. This addendum to the RD/RAWP documents updated information on site conditions including contaminant mass characterization, presents the design for Enhanced Bioremediation (EBR) implementation, and describes the planned construction, implementation, and monitoring of the EBR phase of the remedial action at Site ST012, at the former Williams Air Force Base in Mesa, Arizona.

We would appreciate receiving your comments or concurrence on the attached report within 30 days of receiving these materials. If we do not receive comments after 30 days, we will proceed to publish the final report.

Please contact me at (315) 356-0810 or catherine.jerrard@us.af.mil if you have any questions regarding this report.

Sincerely,

CATHERINE JERRARD, PE
BRAC Environmental Coordinator

Attachment:

Draft Addendum #2 Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona

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AFCEC – Catherine Jerrard (1 and 1 CD)
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File

DRAFT
ADDENDUM #2
REMEDIAL DESIGN AND REMEDIAL ACTION WORK PLAN
FOR OPERABLE UNIT 2
REVISED GROUNDWATER REMEDY
SITE ST012
FORMER WILLIAMS AIR FORCE BASE, MESA, ARIZONA

Prepared for:
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2261 Hughes Avenue, Suite 155
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Prepared by:
Amec Foster Wheeler Environment & Infrastructure, Inc.
4600 E. Washington Street, Suite 600
Phoenix, Arizona 85034

30 November 2015

Contract Number: FA8903-09-D-8572 - 0002
Project No. 9101110001
CDRL No. A001

SIGNATURE PAGE

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LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
µg/L	micrograms per liter
3D	three-dimensional
AMEC	AMEC Environment & Infrastructure, Inc. (now known as Amec Foster Wheeler Environment & Infrastructure, Inc.)
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
bgs	below ground surface
BTEX+N	benzene, toluene, ethylbenzene, total xylenes, and naphthalene
COC	chemical of concern
COPC	chemical of potential concern
CZ	cobble zone
EBR	enhanced bioremediation
EPA	U.S. Environmental Protection Agency
ft	feet, foot
g/L	grams per liter
GAC	granular activated carbon
gpm	gallons per minute
HASP	Site-Specific Health and Safety Plan
JP-4	jet petroleum fuel grade 4
lb(s)	pound(s)
LNAPL	light non-aqueous phase liquid
LPZ	Low Permeability Zone
LSZ	Lower Saturated Zone
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MPE	multi-phase extraction
OU	Operable Unit
PDI	Pre-Design Investigation
PIANO	paraffin, isoparaffin, aromatic, naphthalene, and olefin
QAPP/SAP	Quality Assurance Project Plan/Sampling and Analysis Plan
RA	Remedial Action
RAO	Remedial Action Objective
RD	Remedial Design
RAWP	Remedial Action Work Plan
RODA	Record of Decision Amendment
ROI	radius of influence
SEE	steam enhanced extraction
SOP	standard operating procedure
ST012	Site ST012, the former Liquid Fuels Storage Area
TEA	terminal electron acceptor
TerraTherm	TerraTherm, Inc.
TestAmerica	TestAmerica, Inc.
TIZ	Thermal Influence Zone

LIST OF ACRONYMS AND ABBREVIATIONS (CONT.)

TMP	temperature monitoring point
TPH	total petroleum hydrocarbons
TTZ	Thermal Treatment Zone
UWBZ	Upper Water Bearing Zone
VFD	variable frequency drive
VOC	volatile organic compound

1.0 INTRODUCTION

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler; previously known as AMEC Environment & Infrastructure, Inc. [AMEC]) has developed this work plan for the implementation of enhanced bioremediation (EBR) as part of the remedial action (RA) at the Former Williams Air Force Base (Figure 1-1) for the Former Liquid Fuel Storage Facility (ST012) site (Figures 1-2 and 1-3). This work plan has been prepared on behalf of the Air Force as part of the Performance-Based Remediation at Former Williams Air Force Base Contract (Contract Number FA8903-09-D-8572-0002).

1.1 Purpose of the Report

The RA at the site is detailed in the Final Remedial Design and Remedial Action Work Plan (RD/RAWP) (AMEC, 2014a) and includes steam enhanced extraction (SEE) to be followed by EBR. SEE implementation is currently underway at the site and is estimated to be completed in December 2015. The RD/RAWP presented a conceptual design for EBR but deferred refinement of the EBR design and detail of the EBR implementation until a later time in order to accommodate incorporation of findings collected during SEE and the EBR Field Test (AMEC, 2014a). This addendum to the RD/RAWP documents updated information on site conditions including contaminant mass characterization, presents the design for EBR implementation, and describes the planned construction, implementation, and monitoring of the EBR phase of the RA.

1.2 Organization of the Report

The organization of this addendum follows the development of the RA strategy for EBR implementation. The report consists of eight sections, plus appendices. Section 1.0 presents the purpose and organization of the report. Section 2.0 describes the updated EBR design components. Section 3.0 includes the design of the EBR system. Section 4.0 develops the construction strategy for required site infrastructure improvements. Section 5.0 defines system monitoring procedures and requirements for both performance and compliance monitoring during EBR. Section 6.0 defines the requirements for EBR system shutdown and a selective decommissioning strategy for the EBR system. Section 7.0 provides the anticipated project schedule. Section 8.0 provides references for the works cited in the text. Appendix A presents the updated calculations for modeled extent of light non-aqueous phase liquid (LNAPL). Appendix B presents the corresponding figures by depth interval. Appendix C includes the Enhanced Bioremediation Field Test Report. Appendix D includes the laboratory reports from background sampling. Appendix E presents the outputs from the numerical groundwater model particle tracking. Appendix F presents the calculations for the distribution of terminal electron acceptors (TEAs) between injection wells. Appendix G includes the aquifer arsenic loading calculations. Appendix H includes the Quality Assurance Project Plan/Sampling and Analysis Plan (QAPP/SAP) for the EBR component of the RD/RAWP.

2.0 UPDATED DESIGN COMPONENTS

Several elements of the design basis for EBR as presented in the RD/RAWP have been updated to incorporate new information including:

- an update of the estimate of extent of LNAPL that was present at the site based on the additional boring data collected during installation of the SEE wells;
- an update of extents of heating and estimated mass removal achieved during SEE;
- an update of the estimate of the extent and mass of chemicals of concern (COCs) that will be present at the site following SEE at the initiation of EBR;
- an update of biodegradation and aquifer parameters as estimated by the EBR field test;
- an update of background TEA groundwater concentrations; and
- recalibration of the groundwater numerical model to more recent groundwater elevation conditions.

Each of these elements is described in the following sections.

2.1 Pre-SEE LNAPL Extent Update

Prior to SEE implementation, two sets of LNAPL contours were developed for the site. The first, referred to as the base interpretation, focused on data from the Pre-Design Investigation (PDI) and additionally considered dissolved phase contaminant distribution and where LNAPL had been observed in monitoring wells. The second was a more conservative interpretation that considered data from both historical and PDI borings. These PDI LNAPL Extent Interpretation Update contours were then imported into a three-dimensional (3D) model, which interpolated a surface between the contours to create a 3D representation of the extent of LNAPL contamination. The volumes were further broken down by each impacted hydrostratigraphic unit (in order from shallowest to deepest): the Cobble Zone (CZ), the Upper Water Bearing Zone (UWBZ), the Low Permeability Zone (LPZ), and the Lower Saturated Zone (LSZ). These volumes were used during the design of the SEE system, as described in greater detail in the RD/RAWP (AMEC, 2014a).

After developing the LNAPL-impacted volumes, the mass of LNAPL represented by both the base and conservative volumes was calculated. Two different sets of values were used to estimate LNAPL saturation in each zone: a calculated LNAPL saturation value derived from observed total petroleum hydrocarbons (TPH) analytical data and a literature LNAPL residual saturation value from published laboratory studies of typical values. An estimate for remaining LNAPL was calculated for the volume of the total residual LNAPL. Using the total residual volume, an estimate for the SEE treatment area volume (based on expected SEE system influence) was calculated, and the remaining residual LNAPL volume was designated as the EBR treatment area volume. The resulting PDI LNAPL total residual volume estimates ranged from approximately 850,000 to 1,200,000 gallons (5,600,000 to 8,100,000 pounds [lbs]) of LNAPL remaining at ST012 prior to SEE treatment for the base volume and approximately 1,100,000 to 1,600,000 gallons (7,500,000 to 10,400,000 lbs) for the conservative volume.

The pre-SEE LNAPL Extent Interpretation Update assumes only residual LNAPL at ST012. Between the start of SEE operations and 13 November 2015, greater than 3,500 gallons of mobile LNAPL were removed by bailing and/or pumping from three perimeter monitoring wells (further discussed in Section 2.2.3). The presence of mobile LNAPL during the PDI and the volumes removed during SEE operations indicate that there is mobile LNAPL at ST012; however, it is expected that mobile LNAPL at ST012 is limited in extent compare to residual LNAPL and will be removed via mechanical extraction from wells during both the remainder of SEE operations and EBR system implementation . Because of this, the pre-SEE extent based on residual LNAPL described in this section is used to develop the EBR system design, including required TEA mass calculations.

In preparation for implementation of the SEE remedy, 63 wells were installed throughout the site, including 25 wells in the LSZ. The new wells in the LSZ were installed using the sonic drilling technique and were characterized through all zones to approximately 245 feet (ft) below ground surface (bgs). Information gathered during SEE well installation was used to supplement the existing inputs and to update each of the calculated LNAPL volumes. This interpretation is the most current estimate and is referred to as the pre-SEE LNAPL Extent Interpretation Update. Table 2-1 compares LNAPL mass estimates from the PDI LNAPL Extent Interpretation Update and from the pre-SEE LNAPL Extent Interpretation Update generated for this design effort. The calculations for the pre-SEE LNAPL Extent Interpretation Update are included as Appendix A of this Addendum.

Table 2-1 Pre-SEE LNAPL Extent Interpretation Summary[1]

LNAPL Parameter	EBR Treatment Area Volume		SEE Treatment Area Volume		Total Residual Volume	
	Based on Calculated Average LNAPL Residual	Based On Literature LNAPL Residual	Based on Calculated Average LNAPL Residual	Based On Literature LNAPL Residual	Based on Calculated Average LNAPL	Based On Literature LNAPL
PDI LNAPL Extent Interpretation Update - Base						
Mass Estimate	1,808,946	1,903,866	4,038,834	6,414,476	5,847,779	8,318,342
LNAPL Removed[2]	0	0	228,243	228,243	228,243	228,243
Remaining LNAPL	1,808,946	1,903,866	3,810,591	6,186,233	5,619,536	8,090,099
Pre-SEE LNAPL Extent Interpretation Update - Base						
Mass Estimate	1,240,811	1,523,178	3,312,660	5,435,957	4,553,471	6,959,135
LNAPL Removed[2]	0	0	228,243	228,243	228,243	228,243
Remaining LNAPL	1,294,750	1,652,481	3,030,478	5,078,411	4,325,228	6,730,892
PDI LNAPL Extent Interpretation Update - Conservative						
Mass Estimate	3,178,741	3,485,840	4,591,076	7,187,866	7,769,817	10,673,706
LNAPL Removed[2]	0	0	228,243	228,243	228,243	228,243
Remaining LNAPL	3,178,741	3,485,840	4,362,833	6,959,623	7,541,574	10,445,463

Table 2-1 Pre-SEE LNAPL Extent Interpretation Summary[1]

LNAPL Parameter	EBR Treatment Area Volume		SEE Treatment Area Volume		Total Residual Volume	
	Based on Calculated Average LNAPL Residual	Based On Literature LNAPL Residual	Based on Calculated Average LNAPL Residual	Based On Literature LNAPL Residual	Based on Calculated Average LNAPL	Based On Literature LNAPL
Pre-SEE LNAPL Extent Interpretation Update - Conservative						
Mass Estimate	2,190,819	3,111,703	4,431,183	7,275,286	6,622,001	10,386,990
LNAPL Removed[2]	0	0	228,243	228,243	228,243	228,243
Remaining LNAPL	2,190,819	3,111,703	4,202,940	7,047,043	6,393,758	10,158,747

Notes:

[1] All units are displayed in pounds. Volume of interpreted LNAPL converted to pounds using a conversion factor of 6.57 pounds per gallon of JP-4.

[2] LNAPL Removed based on measurements and estimates of known historical remedial actions at ST012 prior to SEE, as reported in the 2012 Focused Feasibility Study.

EBR - enhanced bioremediation

LNAPL - light non-aqueous phase liquid

PDI - pre-design investigation

SEE - steam enhanced extraction

The pre-SEE LNAPL Extent Interpretation Update resulted in a reduction of the estimated remaining LNAPL residual volume within both the base and conservative volumes. The estimated remaining LNAPL residual for the base volume is approximately 4,300,000 to 6,700,000 lbs and the estimated remaining LNAPL residual for the conservative volume is approximately 6,400,000 to 10,200,000 lbs, accounting for the calculated and literature LNAPL saturations. The base total residual volume decreased approximately 23 and 17 percent (%) for the calculated and literature volume estimates, respectively, and 15 and 2.7% for the calculated and literature volume estimates for the conservative total residual volume, respectively. Figures 2-1 through 2-3 show a visual representation of the base and conservative total residual volumes for three discrete depths at ST012: 160, 180, and 220 ft bgs. Eight supporting figures prepared for different depths at the site are located in Appendix B.

2.2 SEE Performance Update

EBR design parameters are contingent upon the results of SEE operations at the site, including final mass removed, remaining COC groundwater concentrations, observed LNAPL in monitoring wells, and extents where steam temperatures were achieved. Mass removal and temperature data are used to select where to focus initial EBR after steam injection has ceased. The following sections provide a summary of the status of each of these parameters.

2.2.1 SEE Mass Removal

At the time that this report was prepared, SEE treatment was ongoing. Table 2-2 summarizes the total mass removed by SEE treatment since startup on 29 September 2014. Mass in the vapor stream was calculated from daily thermal accelerator influent PID readings and laboratory data.

A correction factor was applied to the PID readings based on the most recent analytical data at the time of each reading. The corrected PID mass loading rate for each day was summed to calculate the total mass removed through vapor and was combined with the measured mass of recovered LNAPL to provide the total mass removed. As of 16 November 2015, approximately 66% of the estimated mass located within the SEE treatment area volume had been removed during SEE treatment using the base model estimate, and approximately 46%using the conservative model estimate. It is expected that the system will continue to remove LNAPL during the remainder of SEE treatment, including both steam-enhanced and post-steam extraction periods. The current progress of SEE at ST012 and the mass removed suggest that the mass present pre-SEE could have been overestimated..

Table 2-2 Total Mass Removed During SEE Operations

Mass Removed	Units	Since Startup (29 September 2014 – 16 November 2015
Total Mass Recovered as LNAPL [1]	lbs	1,118,548
Total Mass Removed as Vapor and Recovered LNAPL[2]	lbs	2,000,197

Notes:
lbs - pounds
[1] Based on volume measured in LNAPL storage tanks and an assumed LNAPL density of 6.57 lbs/gallon.
[2] Based on volume of recovered LNAPL combined with estimated mass removed as vapor (via PID and analytical data).

2.2.2 Groundwater Concentrations

Monthly perimeter monitoring well groundwater sampling is conducted at the site to monitor COC concentrations throughout SEE operations (well locations shown in Figure 2-4). Table 2-3 presents the most recent round of perimeter groundwater monitoring data, as well as the minimum and maximum concentrations measured at each well since startup.

Table 2-3 presents only benzene, toluene, ethylbenzene, total xylenes, and naphthalene (BTEX+N), despite analyzing for the total list of volatile organic compounds (VOCs) (as presented in the ST012 quarterly reports [Amec Foster Wheeler, 2015a, 2015b, and 2015c]). BTEX+N are the only compounds that have consistently exceeded the Operable Unit (OU) 2 Record of Decision Amendment 2 (RODA 2) Cleanup Levels during SEE operations. These compounds are the remaining COCs of primary concern that require treatment to achieve remediation goals.

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Table 2-3 BTEX+N Groundwater Concentrations During SEE Operations

Well ID	OU-2 RODA 2 Cleanup Level (µg/L)	Benzene 5		Ethylbenzene 700		Naphthalene 28		Toluene 1000		Total Xylenes 10,000	
		µg/L	Date	µg/L	Date	µg/L	Date	µg/L	Date	µg/L	Date
ST012-C02	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.17 F	8/3/2015	2.0 U	Multiple
	Max	0.19 F	5/18/2015	1.0 U	Multiple	1.0 U	Multiple	0.26 F	7/13/2015	2.0 U	Multiple
	Most Recent	1.0 U	8/3/2015	1.0 U	8/3/2015	1.0 U	8/3/2015	1.0 U	8/3/2015	2.0 U	8/3/2015
ST012-RB-3A	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.17 F	8/3/2015	2.0 U	Multiple
	Max	1.0 U	Multiple	0.27 F	11/17/2015	1.0 U	Multiple	0.33 F	5/18/2015	0.78 F	4/4/2015
	Most Recent	1.0 U	8/3/2015	1.0 U	8/3/2015	1.0 U	8/3/2015	0.17 F	8/3/2015	2.0 U	8/3/2015
ST012-U02	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.17 F	6/15/2015	2.0 U	Multiple
	Max	0.89 F	6/15/2015	2.0 U	Multiple	2.0 U	Multiple	0.30 F	11/18/2014	4.0 U	8/3/2015
	Most Recent	2.0 U	8/3/2015	2.0 U	8/3/2015	2.0 U	8/3/2015	2.0 U	8/3/2015	4.0 U	8/3/2015
ST012-U11	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.27 F	11/18/2015	2.0 U	Multiple
	Most Recent	1.0 U	8/3/2015	1.0 U	8/3/2015	1.0 U	8/3/2015	0.18 F	8/3/2015	2.0 U	8/3/2015
ST012-U12	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.34 F	11/19/2014	2.0 U	Multiple
	Most Recent	1.0 U	8/3/2015	1.0 U	8/3/2015	1.0 U	8/3/2015	0.21 F	8/3/2015	2.0 U	8/3/2015
ST012-U37	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.22 F	8/3/2015	2.0 U	Multiple
	Most Recent	1.0 U	8/3/2015	1.0 U	8/3/2015	1.0 U	8/3/2015	0.22 F	8/3/2015	2.0 U	8/3/2015
ST012-U38	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	0.26 F	11/19/2014	2.0 U	Multiple
	Most Recent	1.0 U	8/4/2015	1.0 U	8/4/2015	1.0 U	8/4/2015	1.0 U	8/4/2015	2.0 U	8/4/2015
ST012-W11	Min	**34**	10/31/2014	180	10/31/2014	25	10/31/2014	3.6	10/31/2014	89	10/31/2014
	Max	**740**	4/8/2015	**740**	4/8/2015	**62**	4/8/2015	**4,800**	4/8/2015	2,000	4/8/2015
	Most Recent	**740**	4/8/2015	**740**	4/8/2015	**62**	4/8/2015	**4,800**	4/8/2015	2,000	4/8/2015

Table 2-3 BTEX+N Groundwater Concentrations During SEE Operations

Well ID	OU-2 RODA 2 Cleanup Level (µg/L)	Benzene		Ethylbenzene		Naphthalene		Toluene		Total Xylenes	
		5		700		28		1000		10,000	
		µg/L	Date	µg/L	Date	µg/L	Date	µg/L	Date	µg/L	Date
ST012-W12	Min	0.23 F	7/15/2015	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	1.3	6/18/2015	0.85 F	3/11/2015	1.0 U	Multiple	0.36 F	11/18/2014	0.27 F	11/19/2014
	Most Recent	0.51 F	8/5/2015	0.16 F	8/5/2015	1.0 U	8/5/2015	0.2 F	8/5/2015	2.0 U	8/5/2015
ST012-W24	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	**10**	11/18/2014	52	11/18/2014	4.7	11/18/2014	28	11/18/2014	100	11/18/2014
	Most Recent	4.0 U	8/7/2015	4.0 U	8/7/2015	4.0 U	8/7/2015	4.0 U	8/7/2015	8.0 U	8/7/2015
ST012-W29	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	**5.4**	11/18/2014	29	11/18/2014	1.0 U	Multiple	16	11/18/2014	54	11/18/2014
	Most Recent	1.0 U	8/7/2015	1.0 U	8/7/2015	1.0 U	8/7/2015	1.0 U	8/7/2015	2.0 U	8/7/2015
ST012-W30	Min	**1,500**	10/30/2014	240	10/30/2014	26	10/30/2014	1.5	10/30/2014	370	10/30/2014
	Max	**3,900**	6/19/2015	**890**	1/9/2015	**83**	1/9/2015	**2,700**	7/15/2015	1,400	1/9/2015
	Most Recent	**3,400**	8/5/2015	690	8/5/2015	**60**	8/5/2015	**1,700**	8/5/2015	960	8/5/2015
ST012-W34	Min	0.24 F	11/19/2014	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	**7,200**	6/17/2015	560	6/17/2015	**39 F**	6/17/2015	0.31 F	7/14/2015	130	5/20/2015
	Most Recent	**92**	8/4/2015	1.0 U	8/4/2015	1.0 U	8/4/2015	0.21 F	8/4/2015	2.0 U	8/4/2015
ST012-W36	Min	**6.2**	10/30/2014	36	10/30/2014	3.6	10/30/2014	0.31 F	10/30/2014	39	10/30/2014
	Max	**7,400**	5/21/2015	**1,100**	4/8/2015	**150**	4/8/2015	**3,800**	5/21/2015	1,900	5/21/2015
	Most Recent	**3,600**	8/5/2015	470	8/5/2015	**33**	8/5/2015	**1,800**	8/5/2015	1,000	8/5/2015
	Most Recent (DUP)	**3,400**	8/5/2015	430	8/5/2015	**29**	8/5/2015	**1,700**	8/5/2015	920	8/5/2015
ST012-W37	Min	**620**	10/30/2014	580	10/30/2014	**51**	10/30/2014	870	10/30/2014	1,300	10/30/2014
	Max	**18,000**	4/9/2015	**24,000**	4/9/2015	**12,000**	4/9/2015	**36,000**	4/9/2015	**166,000**	4/9/2015
	Most Recent	**18,000**	4/9/2015	**24,000**	4/9/2015	**12,000**	4/9/2015	**36,000**	4/9/2015	**166,000**	4/9/2015
ST012-W38	Min	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	1.0 U	Multiple	2.0 U	Multiple
	Max	**350**	5/20/2015	95	5/20/2015	5.4	5/20/2015	0.38 F	5/20/2015	48	5/20/2015

Table 2-3 BTEX+N Groundwater Concentrations During SEE Operations

Well ID	OU-2 RODA 2 Cleanup Level (µg/L)	Benzene		Ethylbenzene		Naphthalene		Toluene		Total Xylenes	
		5		700		28		1000		10,000	
		µg/L	Date	µg/L	Date	µg/L	Date	µg/L	Date	µg/L	Date
	Most Recent	0.26 F	8/4/2015	1.0 U	8/4/2015	1.0 U	8/4/2015	0.22 F	8/4/2015	2.0 U	8/4/2015
	Most Recent (DUP)	0.24 F	8/4/2015	1.0 U	8/4/2015	1.0 U	8/4/2015	0.22 F	8/4/2015	2.0 U	8/4/2015

<u>**Notes:**</u>
Bold – compound exceeds the OU-2 RODA 2 Cleanup Level
µg/L – micrograms per liter
BTEX+N – benzene, toluene, ethylbenzene, total xylenes, and naphthalene
DUP – duplicate sample
EPA – U.S. Environmental Protection Agency
ft btoc – feet, below top of casing
ID – identification
Max – maximum
Min - minimum
OU-2 RODA 2 – Operable Unit 2 Record of Decision Amendment 2
SEE – Steam Enhanced Extraction

Data Qualifier Definitions:
F – The analyte was detected, estimated above the method detection limit and below the reporting limit
U – The analyte was not detected above the reporting limit

The following perimeter monitoring wells had concentrations exceeding OU-2 RODA 2 Cleanup Levels in the August 2015 sampling event: ST012-W30, ST012-W34, and ST012-W36. Low flow sampling could not be conducted at ST012-W11 and ST012-37 for the August 2015 round of sampling due to the presence of LNAPL in the wells. Given the presence of LNAPL, concentrations can be assumed to exceed the OU-2 RODA 2 Cleanup levels in these wells as was the case for samples obtained at the wells in April 2015. High dissolved COC concentrations make these perimeter wells locations of interest for TEA injections.

2.2.3 LNAPL at Perimeter Monitoring Wells

During SEE operations, perimeter monitoring wells have been gauged on a weekly basis. As part of gauging activities, LNAPL presence and removal have been documented. Starting on 23 December 2014, ST012-W37 developed a measureable layer of LNAPL. Since that time, LNAPL has been removed on a regular basis from the well. Starting on 23 January 2015, ST012-W11 also began to accumulate a measurable LNAPL layer. ST012-W30 also began to periodically accumulate a measureable LNAPL layer starting on 09 June 2015. All three of these well locations historically had measureable LNAPL prior to SEE. The SEE activities have resulted in enhanced mobility of LNAPL in the vicinity of these wells resulting in increased accumulation in the wells. Details regarding LNAPL accumulation in these wells are included in the Soil Vapor Extraction/Steam Enhanced Extraction System Operation and Maintenance Quarterly Reports (Amec Foster Wheeler, 2015a, 2015b, and 2015c). The observed LNAPL accumulation makes these perimeter wells locations of interest for TEA injection.

2.2.4 SEE Temperature Data

Throughout steam operations, soil temperatures have been monitored through the use of individual temperature monitoring points (TMPs) as well as TMPs collocated with extraction wells throughout the thermal treatment zone (TTZ). Individual TMP locations are shown in Figure 2-1. Steam temperatures have been reached throughout the TTZs during SEE operations (as presented in the ST012 quarterly reports [Amec Foster Wheeler, 2015a, 2015b, and 2015c]), and additional heating has also occurred outside of the TTZs. Table 2-4 presents the maximum weekly average and daily average temperatures observed at individual TMPs located outside the TTZs for each hydrostratigraphic zone.

Table 2-4 Maximum Temperatures at Individual TMPs Outside of Each TTZ

Location	CZ			UWBZ			LSZ		
	Highest Weekly Average (°C)	Maximum Daily Average (°C)	Date of Maximum	Highest Weekly Average (°C)	Maximum Daily Average (°C)	Date of Maximum	Highest Weekly Average (°C)	Maximum Daily Average (°C)	Date of Maximum
TMPs Outside All TTZs									
ST012-TMP02	28	29	6/28/2015	29	30	8/8/2015	42	60	6/20/2015
ST012-TMP10	29	30	6/15/2015	38	45	9/28/2015	99	136	9/29/2015
TMPs Outside CZ/UWBZ TTZs									
ST012-TMP03	56	58	9/29/2015	77	118	9/9/2015	-	-	-
ST012-TMP04	61	95	6/15/2015	96	98	6/1/2015	-	-	-
ST012-TMP06	102	103	8/21/2015	120	133	8/22/2015	-	-	-
ST012-TMP07	27	27	8/31/2015	79	129	8/25/2015	-	-	-
ST012-TMP08	61	82	9/15/2015	111	114	8/25/2015	-	-	-
ST012-TMP11	66	99	9/6/2015	65	106	6/8/2015	-	-	-
ST012-TMP14	51	59	9/21/2015	101	123	6/8/2015	-	-	-
ST012-TMP16	79	92	7/20/2015	102	106	7/20/2015	-	-	-

__Notes__:
Highlighted cells indicate that steam temperatures have likely been reached at that location. As per Figure 5.3 from the SEE Design Report (Appendix D of the RD/RAWP), boiling temperatures increase with depth and range from just above 100 °C to 140 °C.
°C – degrees Celsius
CZ – Cobble Zone
LSZ – Lower Saturated Zone
TMPs – temperature monitoring points
TTZs – thermal treatment zones
UWBZ – Upper Water Bearing Zone

Following the end of steam injection, the TTZ and adjacent subsurface temperatures are expected to remain well above ambient temperatures. Health and safety precautions will be required when performing invasive construction and drilling activities at the site after completion of SEE.

2.3 Pre-EBR COC Extent Estimate

The goal of EBR is to reduce the mass of the COCs at ST012 to a level that will promote achieving remedial goals approximately 20 years following the OU-2 RODA 2. Direct analytical data has not been collected during SEE treatment because of the dynamic nature of the subsurface during steam treatment and the hazards associated with steam temperatures in the subsurface. As a result, the remaining COC mass at ST012 was estimated using the updated pre-SEE LNAPL volume estimate (i.e., pre-SEE LNAPL Extent Interpretation Update) described in Section 2.1 as the baseline and applying a theoretical extent of treatment based on observed mass recoveries during SEE operations. The intent is to provide a rough estimate of remaining COC mass to be addressed. The mass estimate will be used to design initial EBR approaches. Given the required assumptions to make these estimates, it is recognized that actual COC mass may be different and require adjustment to EBR approaches as the project progresses.

COC mass remaining at ST012 was estimated using assumed removal percentages for the TTZ and two zones outside of the TTZ. Based on previous SEE experience, treatment within the TTZ was estimated to remove 90% of initial LNAPL mass. Based on observed temperature increases outside of the TTZ (as described in Section 2.2), a zone of treatment (Thermal Influence Zone [TIZ]) was estimated 10 meters outside of the TTZ. Treatment in this zone was not expected to be as effective because temperatures in this zone have been elevated but have not reached steam temperatures as within the TTZ, so removal was estimated at 60%. A third treatment zone (Radius of Influence [ROI] Zone) was estimated 10 meters outside of the TIZ. Treatment was not targeted or expected in the ROI Zone; however, it has been subject to elevated temperatures and influence from the outer extraction wells. Removal in the ROI Zone is estimated at 30%. The LPZ has not been targeted for SEE treatment because of the difficulties related to injecting steam and extracting liquids and vapor from low permeability soils. However, the LPZ has been influenced by thermal conduction from both the UWBZ and the LSZ, so some treatment is to be expected as LNAPL is driven from the liquid to vapor phase. Because of this, treatment of the temperature-affected LPZ adjacent to the TTZ in the UWBZ and LSZ is estimated at 30%.

A summation of BTEX+N was used to focus the remaining COC mass estimate on the COCs of primary concern at ST012 that require reduction to achieve remediation goals, as discussed in Section 2.2.2. Other compounds besides BTEX+N will undergo biodegradation and contribute to the TEA demand at ST012.

During SEE treatment, samples of collected LNAPL were analyzed for paraffin, isoparaffin, aromatic, naphthalene, and olefin (PIANO) analysis. The PIANO analysis was performed on LNAPL recovered through direct removal from site monitoring wells and as extraction fluid recovered from the oil-water separator. The PIANO analysis provides characterization of the LNAPL in percentages based on compound type and each specific compound. A summary of these results are presented in Table 2-5. The average BTEX+N percentage reported during

PIANO analysis (9.1%) was applied to modeled LNAPL volumes to estimate the amount of BTEX+N remaining at the site after SEE treatment.

Table 2-5 Conditioned LNAPL Composition During SEE Treatment By Percentage

Compound Class/ Compound	LNAPL Sampling Date							Average
	1/8/15	2/19/15	3/11/15	3/25/15	4/1/15	5/6/15	6/10/15	
Paraffinic	22.7	23.9	23.1	22.5	22.2	23.3	24.1	23.1
Isoparaffinic	29.0	29.8	29.5	30.0	29.9	24.5	24.7	28.2
Aromatic	19.5	16.3	19.1	18.3	19.0	28.9	30.3	21.6
Benzene	0.28	0.45	0.42	0.47	0.46	0.29	0.18	0.36
Toluene[1]	1.9	0.0	2.4	2.6	2.6	1.9	2.1	2.3
Ethylbenzene	1.9	1.9	2.1	2.0	2.0	2.3	2.5	2.1
Total Xylenes	4.0	4.9	4.2	4.1	5.0	5.1	6.4	4.8
Naphthenic	28.6	29.8	28.1	29.1	28.8	22.3	20.4	26.7
Naphthalene	0.18	0.25	0.25	0.11	0.10	0.67	0.46	0.29
Olefinic	0.16	0.28	0.22	0.17	0.17	0.47	0.42	0.27
BTEX+N Total	8.3	7.5	9.3	9.3	10.2	10.2	11.6	9.1

Notes:
[1] Coelutes with 2,3,3-trimethylpentane. February 19, 2015 data treated as outlier - not included in average.
BTEX+N - benzene, toluene, ethylbenzene, total xylenes, and naphthalene
LNAPL – light non-aqueous phase liquid

A projected estimate for the total LNAPL to be removed during SEE treatment was calculated using removal data reported by TerraTherm in its weekly operations reports. This estimate projects the final LNAPL mass removed by applying a linear LNAPL removal rate calculated during SEE operations between July and November 2015. Based on TerraTherm removal data, this calculation estimates a total of approximately 2,200,000 lbs of LNAPL removed during SEE treatment. Table 2-1 estimates approximately 3,000,000 lbs of LNAPL in the TTZ prior to SEE operations. This corresponds to an approximate removal of 71% of LNAPL from the TTZ. Table 2-6 presents the estimated LNAPL removed at the site after SEE operations. A reduction of the assumed removal percentages was proportionally applied to the TIZ (47.3%) and the ROI and LPZ zones (23.6%). To account for a reduction in the volatile content of the remaining LNAPL due to the increased temperatures in the zones, further reductions in BTEX+N mass were applied in both the TTZ (90%) and TIZ (25%) to estimate the quantity of BTEX+N LNAPL remaining after SEE treatment.

Table 2-6 Summary of Expected COCs Remaining After SEE Treatment

Vertical Zone	LNAPL Removed (pounds)					BTEX + N Remaining (pounds)[1]				
	TTZ	TIZ	ROI	Not Treated	Total	TTZ	TIZ	ROI	Not Treated	Total
Cobble Zone	37,688	7,225	696	0	45,608	99	490	226	94	909
Upper Water Bearing Zone	754,826	169,728	61,239	0	985,793	1,989	12,781	17,891	17,028	49,688
Low Permeability Zone	150,569	0	0	0	150,569	5,040	7,790	6,670	5,069	24,568
Lower Saturated Zone	1,068,937	57,943	6,648	0	1,133,527	2,816	4,363	1,942	2,679	11,801
Total	2,012,020	234,895	68,582	0	2,315,498	9,944	25,424	26,728	24,870	86,966

Notes:

LNAPL removed calculated using projections based on actual data supplied in weekly operations reports supplied by TerraTherm

[1]Fraction of BTEX+N based on LNAPL analysis during SEE. Assumes volatile fraction reductions of 90% in TTZ and 25% in TIZ.

BTEX+N - benzene, toluene, ethylbenzene, xylenes, and naphthalene

LNAPL - light non-aqueous phase liquid

ROI - radius of influence

TTZ - thermal treatment zone

TIZ - thermal influence zone

Data discussed in Section 2.2 regarding LNAPL removed during SEE treatment show that even after accounting for more data acquired during SEE system installation, it is possible that pre-SEE volume estimates were overestimated. To consider this possibility, an adjustment of LNAPL removed and remaining at ST012 after SEE treatment was conducted based on the Total Mass Removed as Vapor and Recovered LNAPL reported by TerraTherm, Inc. (TerraTherm) during weekly SEE operations reporting. This calculation calibrates the modeled estimates using actual data collected from startup through mid-November (Table 2-2) and a projection of removal through the end of December 2015. To adjust the pre-SEE mass estimate from the model using actual data, a calibration ratio was applied by dividing the total LNAPL removed using actual data (2,203,862) by the total LNAPL calculated in the mass estimate (2,941,321). The resulting ratio, 0.75, is applied to the modeled volume estimate to produce the calibrated volume estimate for LNAPL at the site, as shown in Table 2-7.

Table 2-7 Volume Estimate of LNAPL COCs Remaining Using Calibration Ratio

Vertical Zone	LNAPL Removed (pounds)					BTEX+N Remaining (pounds)				
	TTZ	TIZ	ROI	Not Treated	Total	TTZ	TIZ	ROI	Not Treated	Total
Cobble Zone	35,570	6,137	729	0	42,436	36	280	155	71	542
Upper Water Bearing Zone	712,393	160,187	57,797	0	930,376	723	7,315	12,317	12,758	33,114
Low Permeability Zone	157,895	0	0	0	157,895	3,365	5,837	4,997	3,798	17,997
Lower Saturated Zone	1,008,847	54,686	6,274	0	1,069,806	1,024	2,497	1,337	2,008	6,866
Total	1,914,704	221,009	64,800	0	2,200,513	5,148	15,929	18,807	18,634	58,519

Notes:
[1] Fraction of BTEX+N based on LNAPL analysis during SEE. Assumes volatile fraction reductions of 90% in TTZ and 25% in TIZ.
BTEX+N - benzene, toluene, ethylbenzene, xylenes, and naphthalene
COCs – chemicals of concern
LNAPL - light non-aqueous phase liquid
ROI - radius of influence
TIZ - thermal influence zone
TTZ - thermal treatment zone

The mass of BTEX+N remaining as presented in Table 2-6 (upper bound) and Table 2-7 (lower bound) represent the expected range of COCs remaining at the site. Table 2-6 presents the expected mass of BTEX+N remaining at ST012 assuming lower than expected SEE performance and correct pre-SEE total residual volume. Table 2-7 presents the expected mass of BTEX+N remaining at ST012 after applying a calibration ratio accounting for expected SEE treatment system performance, and lower than calculated pre-SEE LNAPL total residual volume estimate at ST012. Based on this model calibration, there are an estimated 59,000 to 987,000 lbs of BTEX+N remaining at the site. The majority of the mass (approximately 33,000 to 52,000 lbs) located in the UWBZ. Approximately 18,000 to 25,000 lbs of BTEX+N are located in the LPZ, which will not be targeted directly with EBR.

2.4 Review of EBR Pilot Test Results

Amec Foster Wheeler conducted an EBR field test and prepared the Enhanced Bioremediation Field Test Report (included as Appendix C) in support of EBR design. The field test included two single well tracer tests, herein also referred to as push-pull tests, using sulfate as a TEA to evaluate delivery and dosing for EBR at ST012 under sulfate reducing conditions. Due to the prevalence of information for aerobic EBR at other sites, the field test only investigated anaerobic EBR to provide data to support evaluation of strategies for aerobic and/or anaerobic degradation of COCs and to support this addendum to the RD/RAWP.

Monitoring wells ST012-W11 and ST012-W30 were selected for the single well tracer tests because they are both located outside of the SEE TTZs and both have historical evidence of LNAPL contamination. Both wells are screened in the LSZ and are located on the United States Army Reserve Property to the west of the SEE TTZs (see Figure 1-3).

The data collected for sulfate degradation from the EBR Field Test indicated that the density of sulfate degrading bacterial populations were higher and that dispersivity values and sulfate utilization rates were more favorable than assumed in RD/RAWP EBR modeling. These findings, in combination with previous studies that concluded sulfate reduction is the dominant naturally occurring process for contaminant assimilation at ST012 (BEM, 1998), indicated that sulfate amendment be included in the EBR strategy. Sulfate amendment can either be used solely or in combination with aerobic methods to achieve remediation goals.

As part of the field test, hydraulic parameters were assessed to aid in future injection strategy design. Water elevations were collected throughout the field test and were evaluated for estimation of hydraulic parameters. However, groundwater elevation data generally showed rapid and abrupt changes during the pull phases which were likely related to fouling of the well screens; this limited the analysis of pull phase data for estimation of hydraulic conductivity. Push phase water level data were unavailable for ST012-W11, and for ST012-W30 the push phase water level data showed several groundwater elevation spikes that corresponded with TEA solution injection rates. Hydraulic results were inconclusive and no refinement to previously modeled hydraulic conductivity values was recommended. However, the hydraulic parameter testing did show that any future use of existing monitoring wells for TEA injection locations should only be considered after redevelopment.

2.5 Background Groundwater Geochemical Analyses

During the 1 September 2015 perimeter monitoring well sampling event, samples from select wells were submitted to TestAmerica, Inc. (TestAmerica), for background geochemical parameters, including metals and cation/anion balance. Samples were taken before and after purging of a minimum of 250 gallons of water from each of three wells. The results of the analyses are presented in Table 2-8. Background sulfate levels were reported as 310 milligrams per liter (mg/L) in the CZ before and after equilibration, 120 before and 180 mg/L after equilibration in the UWBZ, and 100 before and 180 mg/L after equilibration in the LSZ. Iron, a potential TEA, was reported at levels of 32 and 110 micrograms per liter (µg/L) in the CZ and LSZ, respectively, and undetected in the UWBZ after purging. Laboratory reports for this sampling event are included in Appendix D.

2.6 Groundwater Model Particle Tracking

A 3D groundwater model was used for the original RD/RAWP and for design consistency, the same model was used with some parameter updates. Since the model was last used, groundwater elevations have risen across the site. The model was updated with data collected during the two previous annual groundwater monitoring events to better represent hydrostatic conditions at ST012 (prior to SEE influence).

Table 2-8 Baseline Sampling by Sampling Date and ID

Analytic Method	Chemical Name	Units	ST012-C01 9/1/15 7:38	ST012-C01 9/1/15 12:23	ST012-U11 9/1/15 14:03	ST012-U11 9/2/15 7:58	ST012-W12 9/2/15 9:28	ST012-W12 9/2/15 13:33
SM2320B	Alkalinity, Bicarbonate (as CaCO3)	mg/l	100	100	210	210	130	130
SM2320B	Alkalinity, Carbonate (as CaCO3)	mg/l	1.1 U	1.1 U	1.1 U	1.1 U	1.1 U	1.1 U
SM2320B	Alkalinity, Total (as CaCO3)	mg/l	100	100	210	210	130	130
SM2540C	Total Dissolved Solids	mg/l	4,000	NA	2,100	1,300	2,300	NA
SW6010C	Arsenic	µg/L	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U
SW6010C	Barium	µg/L	270	290	490	150	240	150
SW6010C	Cadmium	µg/L	0.45 U	0.45 U	0.45 U	0.45 U	0.45 U	0.45 U
SW6010C	Calcium	µg/L	730,000 D J	790,000 D	830,000 D	280,000	440,000	280,000
SW6010C	Chromium	µg/L	1.6 F	1.5 F	14 F	0.74 F	0.66 U	1.4 F
SW6010C	Iron	µg/L	26 F	32 F	4,400	22 U	22 U	110
SW6010C	Lead	µg/L	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U
SW6010C	Magnesium	µg/L	150,000	140,000	140,000	58,000	93,000	59,000
SW6010C	Manganese	µg/L	0.83 F	3.1 F	100 Q	1.6 F	130 Q	470 Q
SW6010C	Potassium	µg/L	9,900	9,700	11,000	6,200	8,800	7,200
SW6010C	Selenium	µg/L	6.0 F	4.9 U	4.9 U	4.9 U	4.9 U	4.9 U
SW6010C	Silver	µg/L	0.93 U	0.93 U	0.93 U	0.93 U	0.93 U	0.93 U
SW6010C	Sodium	µg/L	110,000	110,000	110,000	68,000	81,000	66,000
SW6010C	Zinc	µg/L	4.5 U	25 F	42 F	4.5 U	5.4 F	11 F
SW7470	Mercury	µg/L	0.027 U	0.027 U	0.027 U	0.027 U	0.027 U	0.027 U
SW8015D	Petroleum Hydrocarbons C10-C28, Diesel Range	mg/l	0.031 U M Q	0.082 F	0.042 F	0.031 U	0.031 U	0.2 F
SW8015G	Petroleum Hydrocarbons C6-C10, Gasoline Range	µg/L	10 U	10 U	10 U	41 M	10 U	1,000 D M Q
SW8260B	1,2,4-Trimethylbenzene	µg/L	0.14 U	0.14 U	0.14 U	0.14 U	0.14 U	29
SW8260B	1,2-Dichloroethane	µg/L	0.13 U	0.13 U	0.13 U	0.13 U	0.13 U	0.13 U
SW8260B	1,3,5-Trimethylbenzene	µg/L	0.14 U	0.14 U	0.14 U	0.14 U	0.14 U	7.8
SW8260B	4-Isopropyltoluene (Cymene)	µg/L	0.17 U	0.17 U	0.17 U	0.17 U	0.17 U	0.68 F
SW8260B	Benzene	µg/L	0.16 U	0.16 U	0.16 U	0.16 U	0.22 F	20
SW8260B	Carbon disulfide	µg/L	0.45 U	0.45 U	0.45 U	0.45 U	0.45 U	0.45 U
SW8260B	cis-1,2-Dichloroethene	µg/L	0.15 U	0.15 U	0.15 U	0.15 U	0.15 U	0.15 U
SW8260B	Cyclohexane	µg/L	0.28 U	0.28 U	0.52 F	2.2	0.28 U	69 D
SW8260B	Ethylbenzene	µg/L	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	92 D
SW8260B	Isopropylbenzene (Cumene)	µg/L	0.19 U	0.19 U	0.19 U	0.19 U	0.19 U	11
SW8260B	m+p-Xylenes	µg/L	0.34 U	0.34 U	0.34 U	0.34 U	0.34 U	66 D
SW8260B	Methyl tertiary butyl ether (MTBE)	µg/L	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
SW8260B	Methylcyclohexane	µg/L	0.36 U	0.36 U	0.44 F	2.1	0.36 U	38
SW8260B	Methylene chloride (Dichloromethane)	µg/L	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U

Table 2-8 Baseline Sampling by Sampling Date and ID

Analytic Method	Chemical Name	Units	ST012-C01 9/1/15 7:38		ST012-C01 9/1/15 12:23		ST012-U11 9/1/15 14:03		ST012-U11 9/2/15 7:58		ST012-W12 9/2/15 9:28		ST012-W12 9/2/15 13:33	
SW8260B	Naphthalene	µg/L	0.26	F	0.22	U	0.22	U	0.22	U	0.22	U	8.8	
SW8260B	n-Butylbenzene	µg/L	0.32	U	0.32	U	0.32	U	0.32	U	0.32	U	0.9	F
SW8260B	n-Hexane	µg/L	0.42	U	0.42	U	0.42	U	1.7	F	0.42	U	9.7	
SW8260B	n-Propylbenzene	µg/L	0.16	U	0.16	U	0.16	U	0.16	U	0.16	U	8.9	
SW8260B	o-Xylene	µg/L	0.19	U	0.19	U	0.19	U	0.19	U	0.19	U	35	D
SW8260B	sec-Butylbenzene (2-Phenylbutane)	µg/L	0.17	U	0.17	U	0.17	U	0.17	U	0.17	U	1.7	
SW8260B	tert-Butylbenzene	µg/L	0.16	U	0.16	U	0.16	U	0.16	U	0.16	U	0.16	U
SW8260B	Tetrachloroethene (PCE)	µg/L	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U
SW8260B	Toluene	µg/L	0.17	U	0.17	U	0.17	F	0.17	U	0.17	U	0.51	F
SW8260B	Trichloroethene (TCE)	µg/L	0.16	U	0.37	F	0.16	U	0.16	U	0.16	U	0.16	U
SW8260B	Trichlorofluoromethane (Freon 11)	µg/L	0.29	U	0.29	U	0.29	U	0.29	U	0.29	U	0.29	U
SW8260B	Vinyl Chloride	µg/L	0.1	U	0.1	U	0.1	U	0.1	U	0.1	U	0.1	U
SW8260B	Xylenes, Total	µg/L	0.19	U	0.19	U	0.19	U	0.19	U	0.19	U	100	
SW9056A	Chloride	mg/l	1,700	D	1,700	D	750	D	540	D	960	D	680	D
SW9056A	Sulfate	mg/l	310	D	310	D	180	D	120	D	180	D	100	D
E300.0	Nitrogen, nitrate	mg/l	13		14		9.5		6.3		3.6		2.2	MS
E300.0	Phosphorus, Total	mg/l	0.079	U	0.079	U	0.079	U	0.079	U	0.079	U	0.079	U MS

Notes:

mg/L - milligrams per liter.
µg/L - micrograms per liter.
MDL - Method Detection Limit.
RL - Reporting Limit.
1. Data reported is not validated and is considered preliminary.

Data Qualifier Definitions:

D - The analyte was detected, sample diluted.
F - The analyte was detected, estimated above the MDL and below the RL.
J – The analyte was detected; however, the result is estimated due to discrepancies in meeting certain analyte specific quality control criteria.
M - The analyte was detected, compound integrated manually.
MS - Matrix spike recovery was low, the associtaed blank spike recovery was acceptable.
NA - Not analyzed
Q – The analyte was detected; however, the result is estimated due to discrepancies in meeting certain analyte specific quality control criteria.
U - The analyte was not detected above the RL.
UJ – The analyte was not detected; however, the result is estimated due to discrepancies in meeting certain analyte specific quality control criteria.

3.0 EBR DESIGN

The primary elements of the EBR design include:

- selection of TEA;
- selection of the TEA distribution strategy including injection/extraction locations and rates; and
- estimation of TEA addition quantities.

Each of these elements is described in the following sections.

3.1 TEA Evaluation and Selection

As part of this addendum to the RD/RAWP, TEA selection has been evaluated based on previous investigations at ST012, literature data, and the EBR Field Test performed in August 2014. The following sections evaluate the two primary TEAs considered (oxygen and sulfate) and present the rationale for the selecting sulfate as the TEA for EBR at ST012.

3.1.1 Oxygen

Historically, aerobic biodegradation has been demonstrated at the site, especially in wells containing high concentrations of dissolved BTEX+N, with dissolved oxygen levels typically measuring below 1 mg/L (BEM, 1998). Oxygen has faster contaminant degradation kinetics than sulfate as a TEA; however, it is limited by its solubility in water. For this reason, hydrogen peroxide was considered as the source of oxygen because it has higher initial solubility and rapidly degrades in situ to release oxygen. Based on the stoichiometry of hydrogen peroxide decomposition in water, for each mole of hydrogen peroxide introduced into groundwater, one-half mole of oxygen can be produced.

Hydrogen peroxide has the highest utilization rate and best utilization factor of considered TEAs: between 0.15 and 0.20 per day and 3.5 lbs of hydrogen peroxide per lb of jet petroleum fuel grade 4 (JP-4) degraded, respectively (BEM 2011, Appendix M). Hydrogen peroxide decomposes quickly to oxygen which limits the extent to which hydrogen peroxide can be distributed in the subsurface before it is transformed. Injected concentrations must also be dilute enough that disinfectant properties of hydrogen peroxide do not limit bacterial populations. For these reasons, hydrogen peroxide would be implemented in a recirculating system with groundwater extraction, hydrogen peroxide addition to extracted groundwater, and reinjection in another well. Infrequent batch hydrogen peroxide injections would likely not be able to deliver sufficient quantities of oxygen to the subsurface. In addition, dissolved oxygen can volatilize and the presence of oxygen bubbles in the saturated zone can potentially reduce hydraulic permeability. Oxygen can also promote fouling by iron oxides.

From a material handling perspective, hydrogen peroxide typically is supplied in 32 or 50% solutions. Such high concentration solutions have health and safety considerations due to hydrogen peroxide's strong oxidizing properties. Because hydrogen peroxide is only available commercially as a solution, between two and three times the mass of pure hydrogen peroxide is required as solution to deliver the required amount of reagent.

3.1.2 Sulfate

Sulfate is a TEA that is utilized by microorganisms under anaerobic conditions. It is estimated that sulfate has a maximum specific benzene utilization rate of between 8.75×10^{-4} and 1.75×10^{-2} per day and a utilization factor of 5 lbs of sulfate per lb of JP-4 degraded (BEM, 2010). This translates into kinetics that are approximate 10 to 100 times lower than the utilization rate for oxygen. However, sulfate is readily utilized in reduced aqueous environments, such as ST012, which has evidence of predominantly sulfate-based biological activity. ST012 has a naturally occurring supply of sulfate replenished by upgradient groundwater, which will serve to continue treatment after active remediation has ended.

Sodium sulfate anhydrous is commercially available as a white, granular, crystalline solid with a purity above 99.0%. Sodium sulfate has a high solubility (up to 427 grams per liter [g/L], or 42.7%), which allows concentrated solutions to be injected in the subsurface. Sodium sulfate will require on-site handling and preparation before injection. Sulfate is not considered a hazardous material, which reduces onsite health and safety concerns when compared to hydrogen peroxide. Details of preparing TEA solid for injection are provided in Section 4.2.

3.1.3 TEA Selection

The primary advantages of oxygen as a TEA over sulfate are the faster degradation kinetics and a more extensive track record than sulfate for enhancement of petroleum hydrocarbon degradation. However, these advantages were offset by several other factors that led to the selection of sulfate as the primary TEA at ST012 including:

- natural site conditions are predominantly based on the activity of sulfate-reducing bacteria;
- influent upgradient background sulfate can supplement sulfate amendments to promote degradation during and after EBR without having to change the dominant bacterial populations or redox conditions;
- sulfate can be introduced into the subsurface at higher concentrations based on the solubility of sulfate and the disinfectant properties of hydrogen peroxide that limit injection of high concentrations;
- sulfate is more stable and will persist longer than hydrogen peroxide, allowing effects of sulfate amendments to continue after injection of sulfate has stopped; and
- sulfate is safer for site personnel to handle.

Oxygen delivered by hydrogen peroxide will remain a consideration in the future, if necessary.

3.2 TEA Injection Strategy

TEA delivery and distribution strategies for sulfate were evaluated for the site and included co-injection with steam during SEE, injection in perimeter wells during the SEE post-steam extraction period, batch injections, batch injections with temporary groundwater extraction, and continuous recirculation systems.

Co-injection of sulfate with steam was considered and ruled out. Co-injection of sulfate would require separate metering pumps that inject sulfate into the pressurized steam well. Given that the focus of EBR will initially be on perimeter contaminant mass, injection of sulfate at interior steam wells is not justified given the coordination with steam operations required.

Batch injections without any extraction was also ruled out based on the likely limited distribution of TEA achieved. This approach would require close injection well spacing to provide effective distribution which is less efficient that batch injections coupled with groundwater extraction to distribute TEA.

The remaining injection strategies are feasible and discussed in the following sections.

3.2.1 Injection During SEE Post-Steam Extraction

After active steam injection, the steam bubble in the subsurface will collapse causing an inward flow of groundwater into the TTZ. For at least a four-week period after active steam injection, the extraction system will remain active to remove any contamination that flows into the TTZ with the inward flowing groundwater.

TEA may be injected in existing monitoring wells U11, U12, W34, and W36, depending on whether implementation can be completed prior to or during the post-steam extraction phase. Injections would be performed using a transportable mix tank and temporary injection equipment to take advantage of the collapsing steam bubble for distributing TEA in the EBR treatment area. Existing monitoring wells used for injection require redevelopment and would only be used if extraction of the amended TEA during this period is unlikely.

3.2.2 TEA Batch Injections with Extraction

Site areas with remaining contamination will be addressed using groundwater extraction with batch injection. Injections will be performed at a set of wells, with extraction wells operated based on expected flow paths developed using the 3D groundwater model. This technique will provide subsurface TEA distribution using sequenced extraction with discrete injection and will allow the operational flexibility to monitor and adjust the locations of injection and extraction during implementation so that TEA distribution targets locations of known contamination.

As shown in Tables 2-6 and 2-7, the bulk of the remaining BTEX+N on site is located outside of the TTZ. New injection and extraction wells will be installed on site to address the remaining contamination. Proposed locations for these wells were determined based on the location of the modeled LNAPL base volume described in Section 2.1 and the updated 3D groundwater model (Figure 3-1). Once the model was recalibrated, select existing monitoring wells and SEE wells, as well as proposed new wells were selected as injection or extraction points. Location selection was based on the pre-EBR COC extent estimates, onsite and offsite constraints (e.g., limitations imposed by property owners or existing utilities and structures), and the distribution of both dissolved COCs and LNAPL in perimeter monitoring wells. Particle tracking was performed originating at each injection point to evaluate the flow path and timeframe to reach the desired extraction point. Through an iterative process, injection and extraction locations were optimized to utilize the natural gradient of the site and to provide better TEA coverage in regions that are predicted to remain impacted by COCs following SEE.

As a result of the particle tracking iterations, it was determined that a constant drawdown approach, as opposed to a constant flow rate for each extraction well, would provide the best TEA distribution based on desired timeframes and the hydrogeology at the site. Appendix E presents the particle tracking results based on the proposed injection and extraction locations shown in Figures D-1 through D-3. In addition, Appendix E presents the estimated flow rate required to maintain a specified drawdown for each extraction well, as well as the estimated travel time from each injection location to extraction location.

Additional well locations may be added based on information collected in the field (e.g. observations during well installation).

Extracted groundwater will be subject to oil-water separation, particulate filtration, and granular activated carbon (GAC) adsorption. The treated groundwater will be used to prepare the TEA solution at a centralized mixing location. The TEA solution will be either pumped to nearby injection wells or transported to remote injection wells. A process flow diagram of the extraction, mixing, and injection process is included as Figure 3-2.

3.2.3 TEA Recirculation

Performance of the batch injection system will be monitored, as discussed in Section 5.0. Based on the performance monitoring data collected during batch injection, it may become necessary to implement a recirculation strategy to increase TEA distribution in specific areas of the site subsurface. A proposed design of an onsite EBR recirculation system was discussed in Appendix E the RD/RAWP. If necessary, elements of the proposed design would be utilized in a future recirculation system onsite, in conjunction with any required update to the groundwater model presented in Appendix E based on data gathered since running the model for presentation in the RD/RAWP.

3.3 TEA Dosage

TEA dosing calculations utilize the following factors to determine the approximate total TEA mass for injection at ST012:

1. Pre-EBR mass extent estimate, developed in Section 2.3,
2. TEA utilization rates and factors, discussed in Section 3.1.2, and
3. Individual areas of well influence, developed in this section.

Individual areas of well influence were determined using Theissen polygons fitted to the injection locations in each vertical layer adjusted by observed groundwater flow contours at the site. The total mass of TEA to be injected was distributed throughout the vertical layers based on the expected mass in each of the individual areas of well influence. Initial target TEA dosage is based on treating approximately 30% of the LNAPL mass in the CZ, UWBZ, and LSZ, on treating approximately 30% of the LNAPL mass in the CZ, UWBZ, and LSZ, accounting for the likelihood that BTEX+N will be preferentially consumed during bioremediation over longer chain hydrocarbons. Although BTEX+N are the primary COCs, other compounds will degrade and consume sulfate in the process. These areas, designated by their corresponding injection wells, and the expected percentage of TEA to be injected are included in Table 3-1. The calculations for the distribution of TEA amongst injection wells uses the lower bound of the estimated remaining mass at ST012 (Appendix F). The percentages are subject to change based on field conditions, including, but not limited to, updated site monitoring data and final installed locations of new wells. Additional TEA may be added to address areas where sulfate becomes depleted based on monitoring data.

Table 3-1 Estimated TEA Injection Mass, by Percentage of Total TEA Mass

Injection Well	Mass of TEA (tons)[1]	Percentage of Zone TEA
CZ		
ST012-CZ22-EBR	12	25.0%
ST012-CZ12-MPE	12	25.0%
ST012-CZ14-MPE	12	25.0%
ST012-CZ16-MPE	12	25.0%
UWBZ		
ST012-UWBZ28-EBR	50	9.7%
ST012-UWBZ29-EBR	38	7.4%
ST012-UWBZ21-MPE	45	8.9%
ST012-UWBZ23-MPE	55	10.7%
ST012-UWBZ32-EBR	45	8.8%
ST012-UWBZ33-EBR	46	9.1%
ST012-UWBZ34-EBR	98	19.3%
ST012-UWBZ35-EBR	38	7.5%
ST012-UWBZ36-EBR	96	18.7%
LSZ		
ST012-W30	43	15.4%
ST012-LSZ51-EBR	12	4.3%
ST012-LSZ50-EBR	44	15.6%
ST012-LSZ49-EBR	34	12.3%
ST012-W11	23	8.2%
ST012-LSZ48-EBR	12	4.3%
ST012-LSZ47-EBR	12	4.3%
ST012-LSZ46-EBR	12	4.3%
ST012-W37	12	4.3%
ST012-LSZ45-EBR	12	4.3%
ST012-W34	12	4.3%
ST012-LSZ44-EBR	12	4.3%

Injection Well	Mass of TEA (tons)[1]	Percentage of Zone TEA
ST012-W36	12	4.3%
ST012-LSZ43-EBR	27	9.8%

Notes:
[1] All wells to be installed during EBR system construction have “-EBR” suffix. All other wells existing.
[2] Based on total TEA mass of 840 tons. Minimum of 12.1 tons injected per injection well.
% - percent
MPE – multi-phase extraction
CZ - cobble zone
TEA - terminal electron acceptor
LSZ - lower saturated zone
UWBZ - upper water bearing zone

As an impurity, sodium sulfate may contain up to 3 milligrams per kilogram (mg/kg) of arsenic. Correspondence with the sodium sulfate supplier has indicated that arsenic levels based on analysis of weekly quality assurance samples between April and July of 2015 fluctuated between 0.5 and 1.4 mg/kg, with an average of 0.96 mg/kg. Historical analytical sampling results indicate that arsenic levels in the area of ST012 have been reported as high as 1.5 µg/L. Background sampling of perimeter monitoring wells reported arsenic levels below laboratory detection limits (Appendix D). A calculation was performed to assess the potential impact of injected arsenic on the aquifer, resulting in an estimated arsenic concentration of between 12 and 36 µg/L after EBR operations (Appendix G). The most stringent aquifer water quality standard is for domestic water use and is 10 µg/L (ADEQ, 2009). The calculation is conservative and does not take into account any of the following expected mechanisms that would be anticipated to decrease arsenic concentrations upon injection:

1. in situ geochemical conditions that would likely lead to precipitation or adsorption,
2. groundwater recharge that will lead to a reduction in dissolved arsenic concentrations, or
3. consumption of arsenic through biotic and abiotic reactions.

Monitoring of arsenic concentrations will be performed during implementation. Any increases of arsenic levels during EBR implementation will be monitored after implementation to confirm arsenic levels are returning to background conditions. Details of this monitoring procedure are discussed in Section 5.0.

4.0 EBR IMPLEMENTATION

EBR implementation will consist of construction activities followed by operation of groundwater extraction and batch injection systems. These phases of implementation are detailed in the following sections.

4.1 EBR Infrastructure Construction

After SEE extraction is completed, TerraTherm will proceed with selective decommissioning of the SEE process equipment that will not be needed for the next phase of RA. Amec Foster Wheeler will reuse as much of the existing process equipment, electrical connections, and utility connections from the SEE treatment system as is practically feasible. Steam injection and liquid extraction piping will remain and will be reused as extraction piping for part of the TEA batch injections discussed in Section 3.3 or recirculation (Section 3.4). Existing steam injection and multiphase extraction wells will remain onsite as part of the EBR system or as potential additional monitoring well locations.

Construction of EBR infrastructure will generally include the following:

- Installation of groundwater extraction and TEA delivery system equipment;
- Installation of supplemental wells for EBR;
- Installation of treatment equipment for extracted groundwater.

Details of infrastructure construction are covered in the following sections.

4.1.1 Post-SEE TEA Injection System Construction

New well pump equipment with high temperature motors will be installed in extraction well locations. Pressure transducers and variable frequency drives (VFDs) will be provided to allow modulation of flow based on drawdown parameters determined during pre-installation modeling efforts and outlined in Section 3.2.2. Electrical connections to the extraction well pumps will be installed in new conduit placed at grade along with any necessary control wiring for use with the pressure transducers and VFD utilized to modulate well drawdown.

Mixing tanks will be installed with secondary containment at a centralized location on site that will be accessible by a forklift and near the location of TEA delivery. Temporary injection manifolds and piping will be installed for use at accessible locations on site. Manifolds will include flow meters, pressure gauges, and ball valves to allow isolation of individual injection lines and monitoring of the system.

For those locations that cannot be reached by temporary piping/hoses, a transfer pump will be installed for transferring injection solution to a mobile injection tank for remote injection. A mobile pumping system, including an injection pump, if necessary, tubing, and a relocatable injection stinger and wellhead cap, will be developed for use at remote injection locations.

4.1.2 Installation of Extraction and Injection Wells

Existing wells from the SEE operations will be used as TEA injection or extraction wells. These will be supplemented with additional injection or extraction wells. Proposed new well locations are shown in Figure 3-1. Locations are based on particle tracking exercises using the numerical groundwater model, as discussed in Section 3.2.2, as well as locations outside of the TTZ where the highest concentrations of COCs were estimated based on the updated contaminant model. Three locations where a well is proposed in both the LSZ and UWBZ will be installed as double-screened wells separated by solid casing and a bentonite plug (packers will be used to isolate treatment regions). Additional well locations could be added based on additional SEE operational data, as well as field observations during initial well installation and injection activities. Table 4-1 shows the proposed injection and extraction wells by name, type, and screened interval.

Table 4-1 Proposed Injection and Extraction Well Construction

Well Identification	Well Type	Screened Interval (ft bgs)
ST012-CZ21-EBR	Extraction	145 - 160
ST012-CZ22-EBR / UWBZ35-EBR	Injection, Double-Screen	145 - 160, 170 - 185
ST012-UWBZ28-EBR / LSZ51-EBR	Injection, Double-Screen	170 - 195, 215 - 225
ST012-UWBZ29-EBR	Injection	170 - 190
ST012-UWBZ30-EBR	Extraction	170 - 190
ST012-UWBZ31-EBR	Extraction	170 - 190
ST012-UWBZ32-EBR / LSZ47-EBR	Injection, Double-Screen	170 - 190, 210 - 230
ST012-UWBZ33-EBR / LSZ48-EBR	Injection, Double-screen	170 - 190, 210 - 230
ST012-UWBZ34-EBR	Injection	170 - 185
ST012-UWBZ36-EBR	Injection	170 - 185
ST012-LSZ43-EBR	Injection	210 - 225
ST012-LSZ44-EBR	Injection	205 - 220
ST012-LSZ45-EBR	Injection	220 – 230
ST012-LSZ46-EBR	Injection	220 – 230
ST012-LSZ49-EBR	Injection	210 – 220
ST012-LSZ50-EBR	Injection	210 – 220

Notes:
ft bgs – feet below ground surface

The drilling subcontractor will drill the well borings using the sonic drilling technique. Sonic drilling is recommended for these borings to produce a continuous lithologic log. This continuous log will allow for accurate visual observations of contamination and PID readings of the cores, provide a complete lithologic record of the subsurface at the well location and facilitate decisions for well construction. Observed evidence of COC impacted soil may result in additional testing or sampling.

The rig setup and drilling schedule will be coordinated so that access remains available for other remediation activities. Following the completion of steam injection at the site, all drilling activities must be coordinated around the potential for encountering formation water well above ambient temperatures and potentially approaching steam temperatures. Remediation wells will be drilled and constructed in accordance with Standard Operating Procedures (SOPs) 4 and 6, as included in the RD/RAWP (AMEC, 2014a). The following instructions generally describe the steps to drill the boring and install the remediation wells (see Figure 4-1 for typical single-screened and double-screened well construction details):

- Advance a minimum 8-inch diameter borehole to the total depth required for each well.
- Record lithology from continuous log collected during borehole advancement (to be performed in accordance with SOP 11).
- Evaluate recovered soil cores (in accordance with SOP 11).
- Review lithology/boring data for possible adjustments to the design screen intervals to target coarser grained soils with likely higher conductivity and/or regions with visible and/or olfactory evidence of residual LNAPL. Geologists will review lithology and well screen intervals with the design team prior to initiating well construction.
- For single-screened wells:
    - Install a 4-inch, 0.010-inch machine-slotted PVC well screen with Schedule 40 threaded connections over the screened interval indicated in Table 4-1.
    - Connect a 4-inch Schedule 40 PVC casing to the well screen from the top of the screen to a maximum of 8 ft bgs, then use Schedule 80 PVC casing to 6" bgs.
    - Fill the borehole space outside the 4-inch diameter well screen and casing with washed #10 – 20 silica sand filter pack from the bottom of the well to the top of the well screen.
- For double-screened wells:
    - Install a 4-inch, 0.010-inch machine-slotted PVC well deep intake screen with Schedule 40 threaded connections over the deep screen interval indicated.
    - Connect a 4-inch Schedule 40 PVC casing to the well screen from the top of the deep screen to the depth indicated.
    - Install a 4-inch, 0.010-inch machine-slotted PVC well upper discharge screen with Schedule 40 threaded connections over the upper screened interval indicated in Table 4-1.
    - Connect a 4-inch Schedule 40 PVC casing to the well screen from the top of the shallow screen to a maximum of 8 ft bgs, then use Schedule 80 PVC casing to 2 ft above ground surface.
    - Fill the borehole space outside the 4-inch diameter deep screen and casing with washed #10 – 20 silica sand filter pack from the bottom of the well to 2 ft above the top of the deep screen.

  - Install a bentonite seal from 2 ft above the top of the deep screen to 2 ft below the bottom of the shallow screen.
  - Fill the borehole space outside the 4-inch diameter shallow screen and casing with washed #10 – 20 silica sand filter pack.
- Install a 5 ft bentonite seal.
- Install a bentonite-cement grout from the bentonite seal to twelve inches bgs where a well vault will be installed with a minimum 12-inch diameter removable access cover.
- Allow the grout seals to hydrate for at least 48 hours after installation.

After installing the wells and allowing the bentonite grout seal to set, the drilling subcontractor/project geologist will develop the wells by mechanical surging and sand bailing, airlift pumping, and/or over pumping, to remove accumulated fines from the base of the wells (developing the screened interval may bring fines into the wells). Well development will be performed in accordance with SOP 7B provided in Appendix H. In addition, existing monitoring wells that will be used for injection or extraction, including U11, W11, W30, W34, W36, and W37, will be redeveloped for use as injection wells during EBR implementation. Table 4-2 summarizes the construction details for existing wells to be used as injection or extraction locations, as shown in Figure 3-1.

Table 4-2 Existing Well Construction and Proposed Use

Well ID	Screened Interval (ft bgs)	Current Use	Proposed Use
ST012-U11	160 – 195	MW	Injection
ST012-W11	208 – 248	MW	Injection
ST012-W30	211 – 251	MW	Injection
ST012-W34	210 – 245	MW	Injection
ST012-W36	210 – 245	MW	Injection
ST012-W37	210 – 245	MW	Injection
ST012-CZ12	145 - 160	MPE	Injection
ST012-CZ14	145 - 160	MPE	Injection
ST012-CZ16	145 - 160	MPE	Injection
ST012-UWBZ21	170 - 195	MPE	Injection
ST012-UWBZ23	170 - 195	MPE	Injection
ST012-CZ18	145 - 160	MPE	Extraction
ST012-CZ19	145 - 160	MPE	Extraction
ST012-UWBZ10	170 - 195	SIW	Extraction
ST012-UWBZ22	170 - 195	MPE	Extraction
ST012-UWBZ26	170 - 195	MPE	Extraction
ST012-UWBZ27	170 - 195	MPE	Extraction
ST012-LSZ17	206.2 - 241.8	MPE	Extraction
ST012-LSZ28	210 - 245	MPE	Extraction

Table 4-2 Existing Well Construction and Proposed Use

Well ID	Screened Interval (ft bgs)	Current Use	Proposed Use
ST012-LSZ18	210 - 245	SIW	Extraction
ST012-LSZ29	210 - 245	MPE	Extraction
ST012-LSZ14	204.8 - 239.8	MPE	Extraction
ST012-LSZ26	210 - 245	SIW	Extraction
ST012-LSZ12	207 - 243	MPE	Extraction
ST012-LSZ36	210 - 245	MPE	Extraction
ST012-LSZ11	206.4 - 243.4	MPE	Extraction
ST012-LSZ35	210 - 245	MPE	Extraction
ST012-LSZ39	210 - 245	MPE	Extraction
ST012-LSZ23	210 - 245	SIW	Extraction
ST012-LSZ38	210 - 245	MPE	Extraction
ST012-LSZ09	205.5 - 240.5	SIW	Extraction
ST012-LSZ37	210 - 245	MPE	Extraction

Notes:
ft bgs – feet below ground surface
ID – identification
MPE – multiphase extraction
SIW – steam injection well
MW – monitoring well

Following well development, well pumps and packers will be installed where necessary. Each extraction well will be equipped with a submersible pump and pressure transducer connected to a VFD to maintain a set drawdown at each well as determined by the groundwater modeling. Figure 4-1 shows the well details for single-screened and double-screened injection wells, as well as for a single-screened extraction well.

4.1.3 Installation of Groundwater Extraction Treatment Equipment

Groundwater extracted during EBR implementation will be subject to treatment before either reuse as part of the injection solution or discharge into the City of Mesa sewer system. Groundwater treatment will include LNAPL removal using an oil-water separator, particulate filtration using bag filters, and dissolved VOC treatment using GAC adsorption. A process flow diagram for the EBR system is included as Figure 3-2.

The expected groundwater extraction flow rate is approximately 100 gallons per minute. Bag filtration and GAC adsorption will use existing process equipment currently utilized by the SEE system. An existing oil-water separator, previously used at ST012 during containment system operations, will be used as part of the treatment train, pending an assessment of its current condition. Where possible, existing SEE piping will be used to connect the groundwater treatment system. All reused equipment will be evaluated for effective use at the expected groundwater flow rate.

The groundwater treatment system will be designed with interlocking controls. These controls will include level, pressure, and flow monitoring to protect the equipment and prevent unintended releases of contamination.

4.1.4 Modification of EBR System for TEA Distribution

In the event adjustments to injection/extraction patterns or a recirculation component is required as part of the EBR operations, as discussed in Section 3.2.3, existing steam injection and extraction piping and wells may be retrofitted for use as additional TEA recirculation system extraction wells. The groundwater treatment equipment described in Section 4.1.3 will be utilized to treat extraction groundwater prior to its reinjection into the subsurface. Additional wells and connections to existing piping may be necessary to complete the onsite recirculation system.

4.2 Operation

This section outlines the general guidelines for operation of the EBR system. Specific operations of the unit processes will be determined prior to field implementation based on system testing as part of commissioning. Specific operations instructions will be documented in EBR SOPs developed during and following system commissioning. SOPs will be appended to this addendum and maintained on site during active EBR activities.

4.2.1 TEA Delivery, Storage, and Handling

Sodium sulfate (anhydrous) is a non-hazardous white crystalline solid and will be delivered in self-contained 2,200-lb bulk bags equipped with spouts on the bottom of the bag for material transfer with minimal generation of particulate dust. The material will be delivered and stored in standard 53-ft trailers on an as needed basis. Due to the anticipated mixing and injection schedule, it is likely that there will be at least one 53-ft trailer onsite daily during injection activities. Because the sodium sulfate is anhydrous and hygroscopic, storage of excess material onsite will be minimized because the material will readily absorb water, solidifying the material within the bulk bag making it difficult to handle.

Bulk bag handling will require an onsite reach forklift with a qualified operator. Mixing and batch preparation of TEA solutions using bulk bags will require at least two onsite personnel and will require safety considerations including management of particulates and working around elevated loads. These considerations will be addressed in the updated site-specific health and safety plan (HASP).

4.2.2 TEA Dosing

In order to minimize the amount of labor and time required to inject TEA into the subsurface, batches of TEA solution will be prepared at a target concentration of approximately 320 g/L, which is approximately 75% of the solubility of sodium sulfate in water at ambient temperature. The actual solution concentration will be modified in the field as required to generate the highest working concentration solution achievable given extracted groundwater geochemistry and ambient temperatures. Lower concentration solutions may be prepared based on injection logistics including injection location, overall target sulfate dosage and injection duration. Bulk bags of sodium sulfate will be emptied into mix tanks using a reach forklift, or similar material handling equipment, and will be mixed prior to injection to ensure solution uniformity. Concentrations of TEA batches will be confirmed with field sampling kits prior to injection for accuracy (see Table 5-1 for sampling frequency and detail).

Details of specific TEA handling procedures will be included in the EBR SOPs. The site HASP will be updated to reflect new activities associated with TEA dosing, including forklift (or equivalent) usage, working with an elevated load, and emptying a bulk bag.

4.2.3 Micronutrient Dosing

Microorganisms not only require electron donors and TEAs to facilitate cell growth and maintain energy, but also need certain other trace elements at much lower concentrations. Micronutrients such as iron, nickel, cobalt, molybdenum and zinc, are typically abundant enough in aquifer minerals that no additional dosing is required. However, in some circumstances, biodegradation of COCs can stall due to a lack of micronutrients. In the event that this occurs, a mix of micronutrients, Bionetix MICRO 14, or similar, may be added to TEA injection solutions and injected into the subsurface to increase biological activity.

Details of specific micronutrient handling procedures will be added to the EBR SOPs if necessary. Any required updates to the site-specific HASP due to usage of a micronutrient blend will be added at that time.

4.2.4 Groundwater Extraction Shutdown

TEA dosing using batch injections coupled with groundwater extraction will operate until satisfactory TEA distribution is achieved. TEA distribution will be monitored using methods described in Section 5.0. Additional phases of EBR implementation may be necessary to target residual areas of contamination.

5.0 EBR SAMPLING AND ANALYSIS

EBR baseline and performance monitoring will be conducted to provide data for evaluation of EBR progress as detailed in this section and Appendix H. Prior to the transition from SEE to EBR at the site, steam injection will be discontinued and there will be a period of extraction only. During this phase, routine sampling locations and frequencies will remain as established in the RD/RAWP. Following the SEE phase at the site, monitoring of EBR operations will include a combination of process monitoring (e.g., pressures, flow rates) and analytical monitoring for TEA distribution, microbial activity, and dissolved concentrations of site COCs to evaluate the progression of EBR. This section discusses the performance monitoring specific to the EBR implementation. Table 5-1 summarizes the monitoring, sampling, and analysis methods and frequencies. Sampling programs are further discussed in the following subsections. Additional detail for EBR sampling and analysis is included in the QAPP/SAP for EBR implementation (included as Appendix H).

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
Baseline					
Liquid	• Select SIWs and MPE wells (as listed in Table 4-2). • All newly installed injection and extraction wells (as listed in Table 4-1)	• VOCs (8260B) • SVOCs (8270) • ICP Metals (6010C) • Nitrate and Sulfate (9056A) • Alkalinity (SM 2320B) • Sulfate field screening	• Single event near the end of post-steam extraction activities (existing wells) • At least one week after well development (new wells)	• Performance (Baseline) • Operational Strategy Assessment (adjustments to TEA injection/ extraction strategy)	Yes
Soil	• All drilled locations (drilled using sonic)	• Continuous logging • PID readings	• Approximate 10-foot vertical core intervals or where changes are noted.	• Operational Strategy Assessment (injection/ extraction strategy)	No
		• LNAPL Dye Test Kits	• At core intervals of suspected LNAPL based on odor, staining, or PID readings	• Operational Strategy Assessment (injection/ extraction strategy)	No

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
		• VOCs (EPA 8260B) • TPH (8015B)	• 1 per 10 ft interval where dye test kit is positive	• Operational Strategy Assessment (confirmation of qualitative monitoring/ analysis)	Yes
Injection Well and Injection Solution Sampling					
Liquid	• TEA Injection fluid	• ICP Metals (6010C) • Sulfate (9056A)	• Monthly	• Operational Strategy (verification of TEA concentration)	Yes
Liquid	• New and existing injection locations (24) (as listed in Tables 4-1 and 4-2)	• VOCs (8260B) • ICP Metals (6010C) • Sulfate and Nitrate (9056A)	• Quarterly	• Performance (dissolved VOCs reduction, TEA solution distribution, dissolved metals monitoring)	Yes
Extraction Well Sampling					
Liquid	• New and existing extraction locations (24) (as listed in Tables 4-1 and 4-2 except sampling frequency is higher for wells in next row)[2]	• VOCs (8260B)	• Quarterly	• Performance (dissolved COCs reduction) • Operational Strategy Assessment (bioactivity and TEA distribution)	Yes
Liquid	• New and existing extraction locations (24) (as listed in Tables 4-1 and 4-2 except sampling frequency is higher for wells in next row)[2]	• VOCs (8260B)	• Quarterly	• Performance (dissolved COCs reduction) • Operational Strategy Assessment (bioactivity and TEA distribution)	Yes
		• TPH (8015B) • ICP Metals (6010C)	• Semiannual	• Performance • Compliance (trace metals monitoring)	Yes
		• Sulfate Field Screening • Sulfate (9056A)	• Biweekly during the first month (sulfate only), then transition to monthly thereafter	• Operational Strategy Assessment (TEA distribution)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
			with confirmatory offsite laboratory analysis (9056A) for every 10% of field screening samples • Monthly at extraction wells once extraction turned off • pH and temperature monitoring will stop following shutoff of extraction well		
Liquid	Select extraction wells: • ST012-CZ18 • ST012-CZ19 • ST012-CZ21 • ST012-UWBZ31 • ST012-LSZ39	• Sulfate Field Screening • Sulfate (9056A)	• Weekly during the first two months, then transition to monthly thereafter with confirmatory offsite laboratory analysis for every 10% of field screening samples	• Operational Strategy Assessment (TEA distribution)	Yes
Groundwater Monitoring Well Sampling					
Liquid	Groundwater monitoring wells[2]: • ST012-C02 • ST012-U02 • ST012-W12 • ST012-U37 • ST012-RB-3A • ST012-W24 • ST012-U38 • ST012-W38 • ST012-U12 • ST012-CZ01 • ST012-CZ05 • ST012-UWBZ19 • ST012-UWBZ24 • ST012-LSZ21 • ST012-LSZ27	• VOCs (8260B) • ICP Metals (6010C) • Sulfate (9056A)	• Quarterly	• Performance (dissolved COCs reduction) • Operational Strategy Assessment (TEA distribution)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
Liquid	• Annual Groundwater Monitoring Locations (see AMEC, 2013 with modified locations per Table 5-3 of the RD/RAWP)	• See AMEC, 2013 with modified locations per Table 5-3 of the RD/RAWP.	• Annual	• Compliance (RODA 2)	No
Process Water Sampling					
Liquid	• Treatment System Influent	• VOCs (8260B)	• Monthly	• Performance (mass removal)	Yes
Liquid	• GAC Influent • GAC Midfluent • GAC Effluent	• VOCs (8260B)[1]	• Weekly for influent and midfluent until influent concentrations stabilize, then monthly, quarterly at effluent	• Performance (mass removal by GAC) • Operation (breakthrough at Midfluent) • Compliance (effluent discharge permit)	Yes
		• SVOCs (8270)[1]	• Monthly[1]		
		• Pesticides/PCBs (8081/8082)[1] • HRGC/HRMS (1699)	• 8081/8082 Monthly with a second sample sent for HRGC/HRMS analysis if there are any detections of prohibited compounds[1]		
	• Effluent Discharge	• Liquid Discharge Flow Rate	• Daily flow meter readings[1]	• Compliance (effluent discharge permit)	No

Notes:

[1] May be modified based on final discharge permit.

[2] Water quality parameters (pH, temperature, DO, and ORP) will be evaluated at each sampled well using a flow through cell and calibrated probes

ASTM – American Society for Testing Materials
DO – dissolved oxygen
FID – flame ionization detector
GAC – granular activated carbon
GC – gas chromatograph
HRGC/HRMS – high resolution gas chromatography /high resolution mass spectrometry
LNAPL – light non-aqueous phase liquid
LSZ – lower saturated zone
MPE – multiphase extraction
ORP – oxidation reduction potential
PCBs – polychlorinated biphenyls
PID – photoionization detector
PLC – programmable logic controller
SEE – steam enhanced extraction
SVOCs- semi-volatile organic compounds
TPH – total petroleum hydrocarbons
VOCs – volatile organic compounds

5.1 Baseline Sampling

Prior to EBR injection and extraction activities, sampling will be conducted to determine baseline conditions and to adjust operational strategy based on conditions in the field.

5.1.1 Pre-EBR Groundwater Sampling

During the final stages of SEE at the site, multi-phase extraction (MPE) wells will be sampled to determine baseline dissolved BTEX+N concentrations within the TTZ at the site. After drilling and well construction activities for new injection and extraction wells are complete, Amec Foster Wheeler will perform an initial round of groundwater sampling to document baseline conditions in the EBR treatment area prior to EBR activities. Results will be used to establish baseline concentrations of COCs/Chemicals of Potential Concern (COPCs) as established in the RODA 2. The following analyses by laboratory will be conducted at all newly installed wells and select MPE wells at the site:

- Sulfate (U.S. Environmental Protection Agency [EPA] Method 9056A)
- ICP Metals (EPA Method 6010C)
- VOCs (EPA Method 8260B)
- SVOCs (EPA Method 8270C)

Baseline sampling will also help evaluate potential adjustments to the injection/extraction strategy.

5.1.2 Soil Characterization for LNAPL

As discussed in Section 4.1.2, all new well cores will be screened with a PID for the presence of VOCs. Dye test kits will be used to confirm LNAPL presence/absence that is suspected based on visual and PID screening. The selection of a core interval for dye testing will be subject to the judgement of the field geologist and will depend on the uncertainty associated with the visual and PID screening methods. It is anticipated that the frequency of dye test kit use will decrease over the investigation period as confidence in visual and PID readings increases. Soil samples with positive dye test kit results will be sent off site for analysis of VOCs by EPA Method 8260B and TPH (sum of gasoline range organics and diesel range organics) by EPA Method 8015B. Results of LNAPL characterization will be used to make adjustments to screened intervals, well layout, and the TEA injection/extraction strategy.

5.2 Injection Well and Injection Solution Sampling

Sampling at individual existing and new injection wells and the injection solution will be used to monitor dissolved VOC concentrations, dissolved metal concentrations, and sulfate concentrations. Injection monitoring will help assess and necessary changes to injection/extraction strategy.

5.2.1 TEA Injection Solution Sampling

On a monthly basis, TEA injection solution samples will be collected to confirm injection solution concentration. TEA injection solution will be analyzed on a monthly basis for dissolved metals concentrations via EPA Method 6010C to confirm quality assurance reports received from the TEA supplier regarding the arsenic concentration in TEA.

5.2.2 Injection Well Sampling

Each existing and new injection well will be sampled and analyzed for VOCs via EPA Method 8260B, dissolved metals vis EPA Method 6010C, and for sulfate and nitrate via EPA Method 9056A to monitor: TEA distribution, progress in reduction of dissolved VOCs, and any changes in dissolved metals within the formation that may have resulted from TEA solution injections.

5.3 Extraction Well Sampling

During EBR activities, each extraction well (24 wells total) will be sampled and analyzed for VOCs (BTEX+N) via EPA Method 8260B. BTEX+N monitoring at individual extraction wells will help document progress towards the transition to monitoring.

On a semiannual basis, all 24 extraction wells will be sampled and analyzed for TPH via EPA Method 8015B and ICP Metals via EPA Method 6010C. TPH will be monitored to document the general changes in groundwater petroleum hydrocarbons beyond the COCs. ICP Metals analysis will be conducted to document any changes in dissolved metals within the formation that may have resulted from TEA solution injections.

Extracted groundwater from individual wells will be monitored throughout EBR activities to determine if and at what rate TEA is being distributed between injection and extraction points. Based on groundwater model results, TEA travel times will vary between different injection/extraction well pairs. The following extraction wells are predicted to have a short timeframe (less than two months) to TEA breakthrough and will be monitored on a weekly basis using sulfate field test kits:

- ST012-CZ18
- ST012-CZ19
- ST012-CZ21-EBR
- ST012-UWBZ31
- ST012-LSZ39

In addition, 10% of sulfate field test kit samples will also be analyzed for sulfate offsite via EPA Method 9056A to verify field test results. The remaining 19 extraction wells will be monitored on a biweekly basis for the first 3 months, then will transition to monthly sampling thereafter. Following TEA breakthrough, each extraction well will continue to be sampled and analyzed via the sulfate field test kits on a monthly basis with 10% of samples being sent offsite for sulfate analysis. Modifications to the field test kit/laboratory analysis may be proposed based on the correlations between these methods observed.

5.4 Groundwater Monitoring Well Sampling

Monitoring wells will be used as sampling locations to provide additional dissolved groundwater concentrations data throughout the site.

Perimeter monitoring wells (including those being used as injection points) will continue to be gauged and bailed (if necessary) for LNAPL on a monthly basis for the first six months of EBR activities, and will transition to a quarterly basis thereafter.

5.4.1 Quarterly Groundwater Monitoring

Samples from 10 perimeter monitoring wells and six select MPE wells/Steam Injection Wells within the TTZ will be analyzed for the following on a quarterly basis:

- VOCs (BTEX+N) via EPA Method 8260B
- ICP Metals via EPA Method 6010C
- Sulfate via EPA Method 9056A
- TPH via EPA Method 8015B

5.4.2 Annual Groundwater Monitoring

Annual groundwater monitoring will continue at the site in accordance with the Groundwater Monitoring Work Plan (AMEC, 2013).

5.5 Process Water Sampling

Liquid samples will be collected from the GAC influent and midfluent to monitor for contaminant breakthrough. Liquid samples will be submitted for laboratory analysis for VOCs via EPA Method 8260B on a weekly basis.

Liquid samples will be collected from the GAC effluent to monitor for contaminant breakthrough and to document discharge compliance. Liquid samples will be submitted for laboratory analysis for the following:

- VOCs via EPA Method 8260B on a monthly basis
- Pesticide/polychlorinated biphenyls via EPA SW846 Method 8081/8082 on a monthly basis
- High Resolution Gas Chromatography/High Resolution Mass Spectrometry via EPA Method 1699 (when necessary to verify any pesticides detections that may occur)
- Semi-volatile organics via EPA Method 8270C on a monthly basis

These analyses are subject to change pending updates to the sewer discharge permit.

In addition to chemical analysis, discharge flow rate will be monitored via daily flow meter readings to ensure compliance with the maximum daily discharge flowrate as designated in the sewer discharge permit.

5.6 EBR Reporting

Status and data summaries will be presented as part of the routine Base Realignment and Closure Cleanup Team calls and meetings. Validated data, including laboratory analyses and operational data, will be presented on a quarterly basis with the current quarterly soil vapor extraction progress reports for ST012. Discharge monitoring reports will be submitted as required by the sewer discharge permit. Copies of discharge monitoring reports will be included in the quarterly reports.

6.0 EBR SYSTEM SHUTDOWN AND DECOMMISSIONING

This section identifies how the decision to transition from active EBR to monitoring will be made and describes the decommissioning process for the active EBR system.

6.1 Requirements for EBR System Shutdown

EBR will be implemented to achieve conditions (residual COC/ [COPC groundwater concentrations) at ST012 such that contaminants will degrade by natural attenuation to achieve the cleanup levels within the projected remedial timeframe (i.e., about 20 years) after completion of EBR. The EBR system is designed with the anticipation that a steady state flux of sulfate into the treatment zone from upgradient of the site will continue so that ongoing biodegradation will satisfy the final remedial goal for ST012. Additional phases of EBR may be necessary to target residual areas of contamination. A further discussion of the transition from EBR to monitoring is discussed in Section 4.3.3 and Appendix E of the RD/RAWP. It is anticipated that the transition to monitoring will be supported by updates to the groundwater model using data from EBR for contaminant and sulfate concentrations to show projected conditions in the future consistent with the RAOs and Cleanup Levels.

6.2 Selective Decommissioning of EBR System

Once subsurface conditions have met remedial goals for transition to monitoring, the EBR system will be decommissioned and dismantled. Downhole pump components and associated electrical and controls components will be removed from extraction wells, and wellheads will be removed and wells prepared for use as monitoring locations until a time when they may be abandoned.

Process equipment will be disconnected and decontaminated as required, working from process inlet to treatment effluent to continue processing fluids in the system. Once the system can no longer process any contaminated fluids, fluids will be containerized and characterized for off-site disposal. All non-hazardous process equipment and materials will be either removed from the site for reuse or loaded into dumpsters for offsite disposal or recycling. Rental equipment and temporary facilities will be returned to vendors as appropriate.

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7.0 PROJECT SCHEDULE

The anticipated project schedule, including design, procurement, and implementation activities, is included as Figure 7-1. The schedule is based on assumed dates for shutdown of steam injection and the post-steam extraction period and is subject to change based on actual SEE dates.

Adjustment for operational duration and future EBR system modifications will be developed and the schedule updated.

8.0 REFERENCES

AMEC Environment and Infrastructure, Inc. (AMEC), 2013. *Final Groundwater Monitoring Work Plan, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona*. September 24, 2013.

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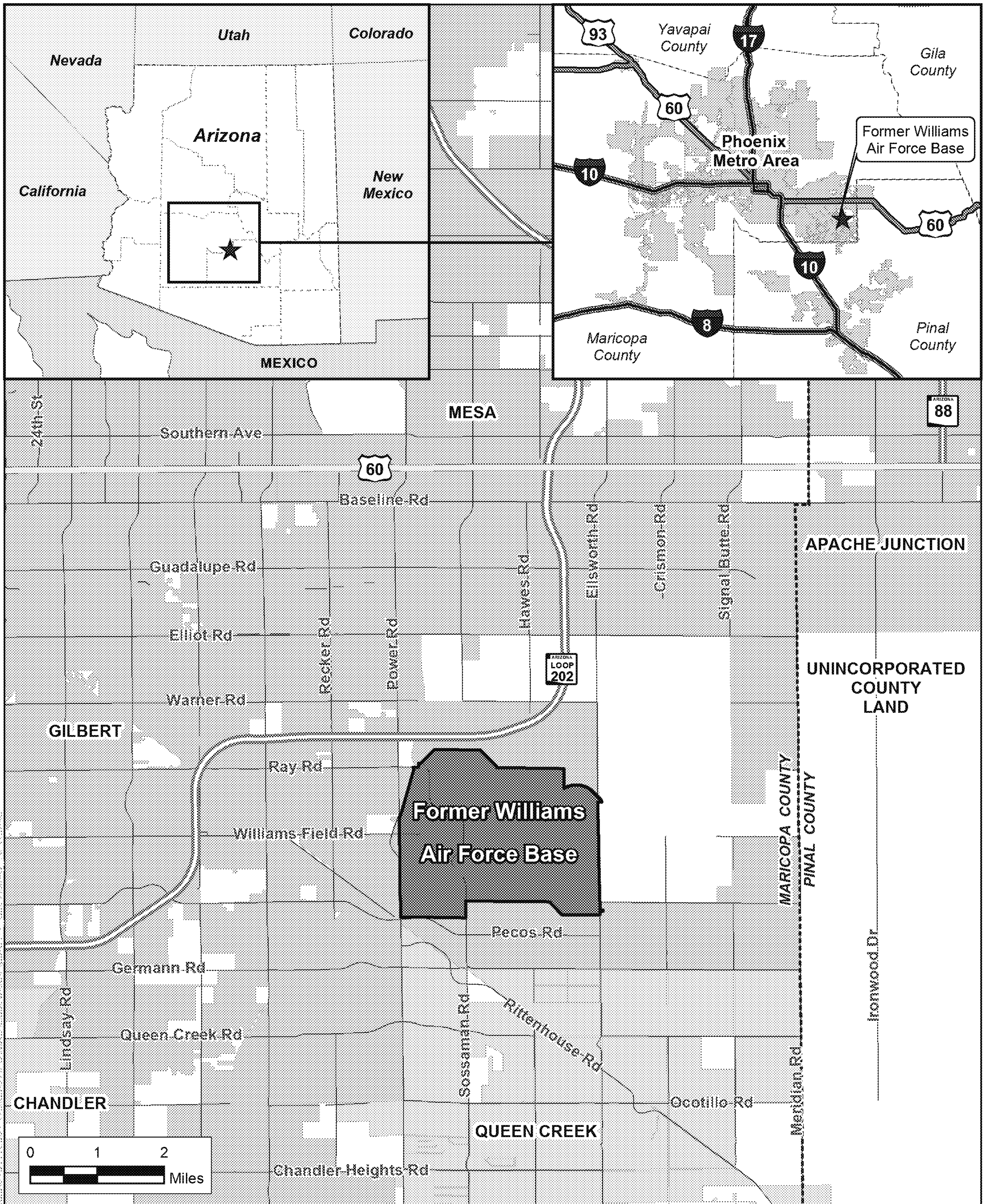
FIGURES



Job No.:	9101110001
PM:	EW
Date:	1/28/2015
Scale:	1" = 2 miles

N

Former Williams Air Force Base
Mesa, Arizona

Location of Former Williams Air Force Base

FIGURE
1-1

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Job No.:	9101110001
PM:	DS
Date:	9/30/2015
Scale:	1" = 0.5 mile

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Former Williams Air Force Base
Mesa, Arizona

ST012 Site Location Map

FIGURE
1-2

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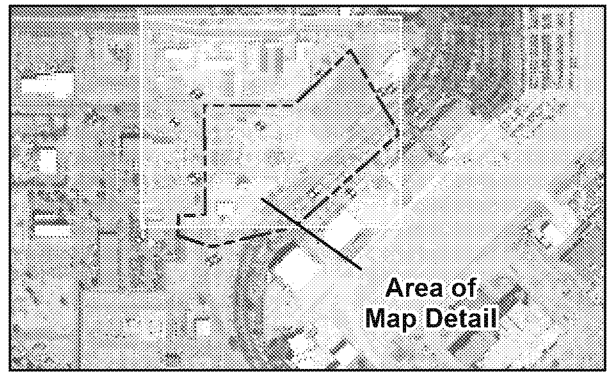

Legend

- Groundwater Monitoring Well Location
- Fence Line
- ST012 Site Boundary

Notes:

ST012-MW12 Monitoring Well Identification

0 25 50 100 Feet

N

Addendum #2
Remedial Design/Remedial Action
Work Plan
Site ST012 - Former Williams Air Force Base
Mesa, Arizona

Perimeter Monitoring Well Locations

FIGURE **1-3**	Job No.:	9101110001
	PM:	DS
	Date:	9/28/2015
	Scale:	1" = 100'

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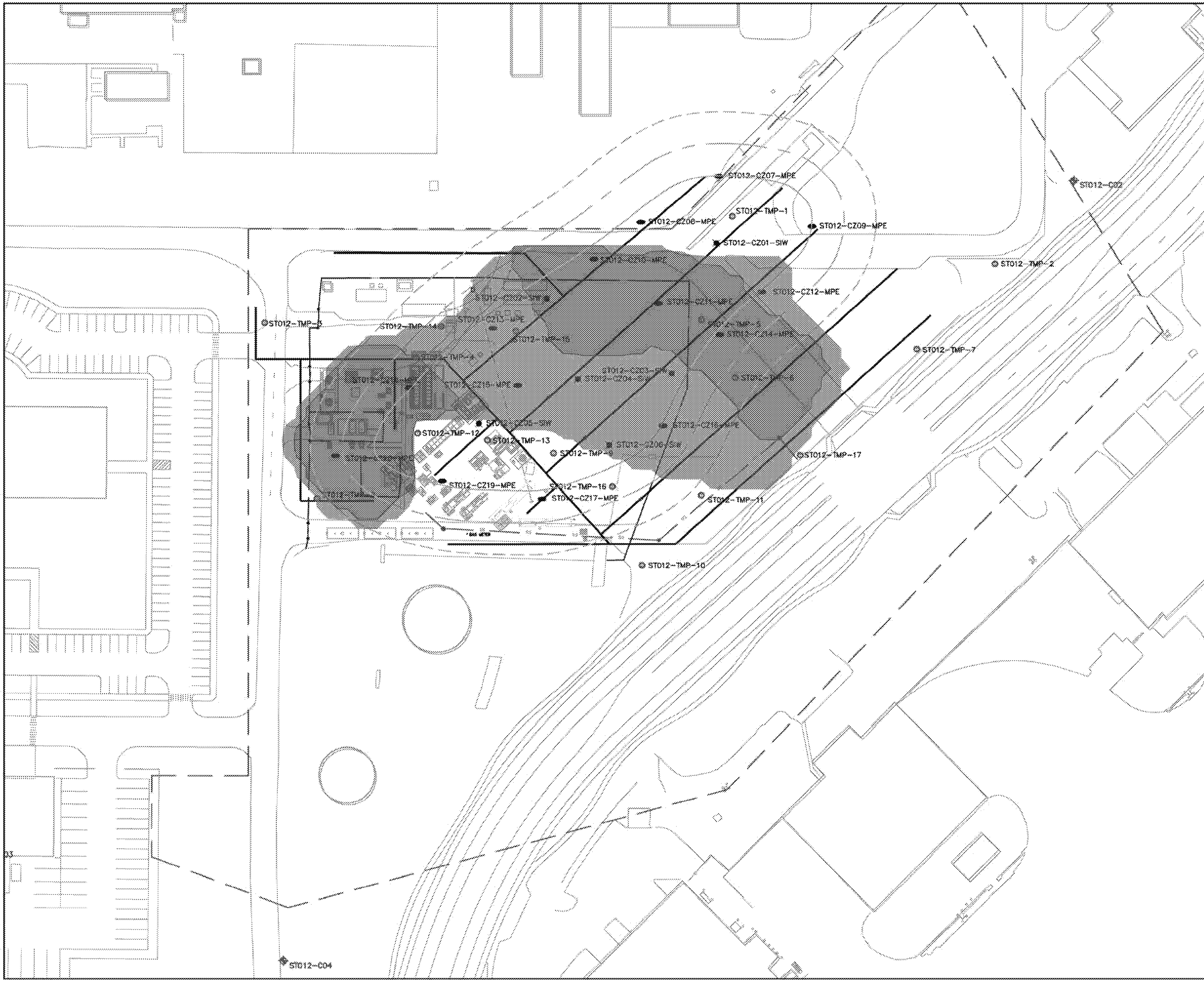

Legend

- PERIMETER MONITORING WELL
- SIW CZ = 6
- MPE CZ = 14
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- CZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

CZ	COBBLE ZONE
LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

N

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent - CZ 160 FT BGS

FIGURE 2-1	
Job No.	9101110001
PM:	EW
Date:	09/28/15
Scale:	1"=100 Feet

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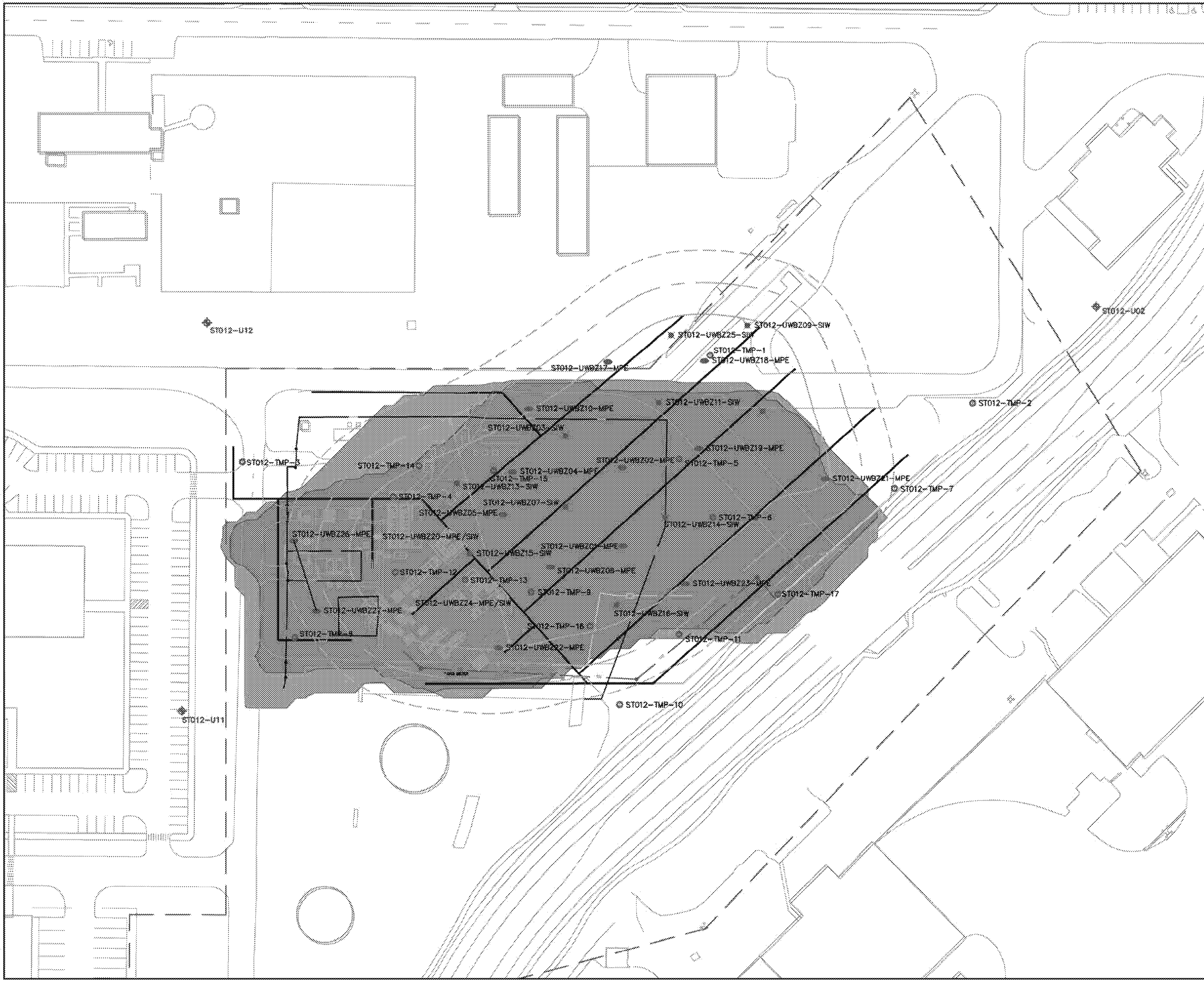

Legend

- PERIMETER MONITORING WELL
- SIW UWBZ = 10
- MPE UWBZ = 14
- DUAL PURPOSE UWBZ = 2
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- UWBZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT
UWBZ	UPPER WATER BEARING ZONE

0 50 100 Feet

N

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent - UWBZ 180 FT BGS

FIGURE 2-2	
Job No.	9101110001
PM:	EW
Date:	09/28/15
Scale:	1"-100 Feet

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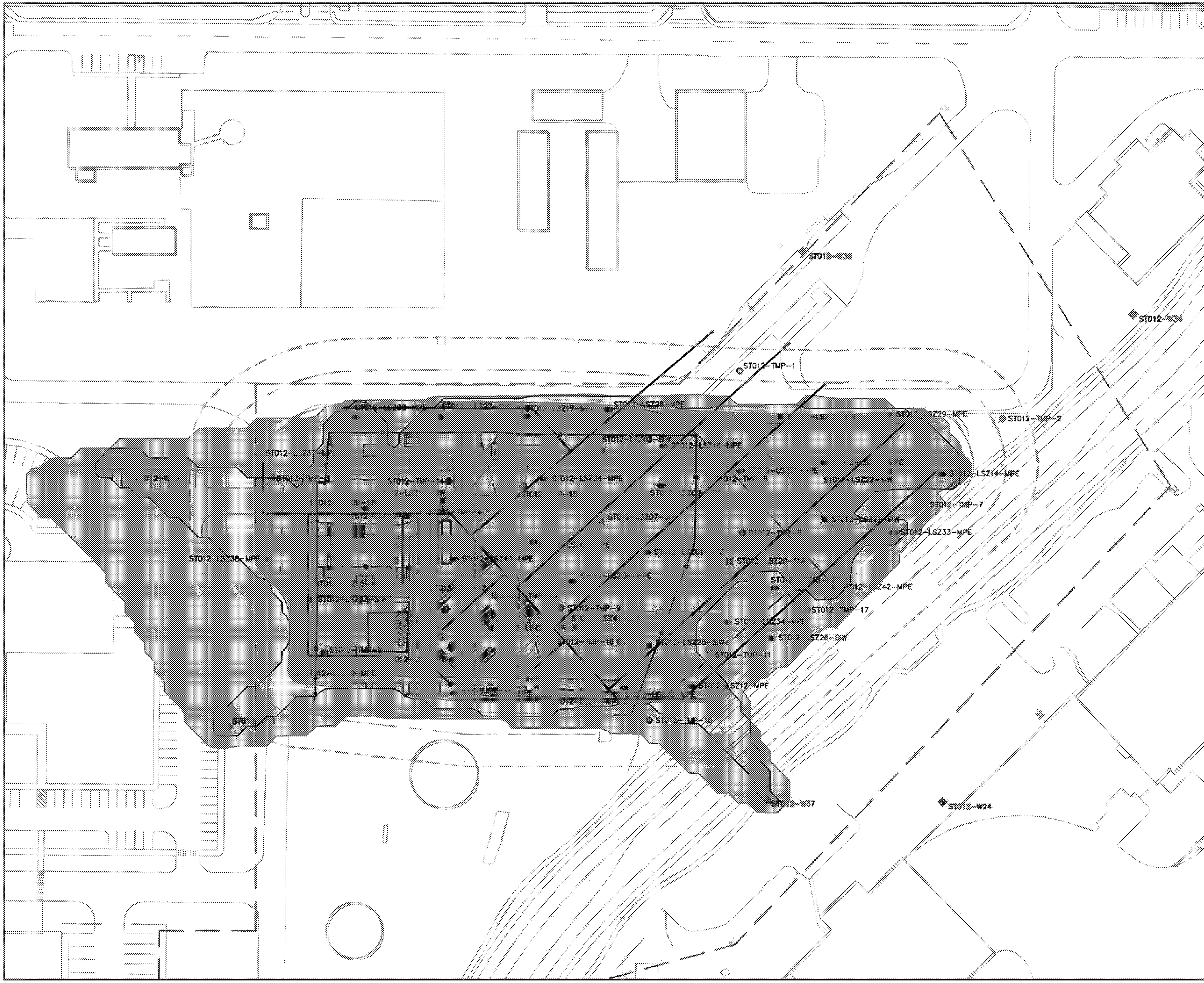


Legend

- PERIMETER MONITORING WELL
- SIW LSZ = 15
- MPE LSZ = 27
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- LSZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL–BASE
- MODEL EXTENT OF RESIDUAL LNAPL–CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LSZ	LOWER SATURATED ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

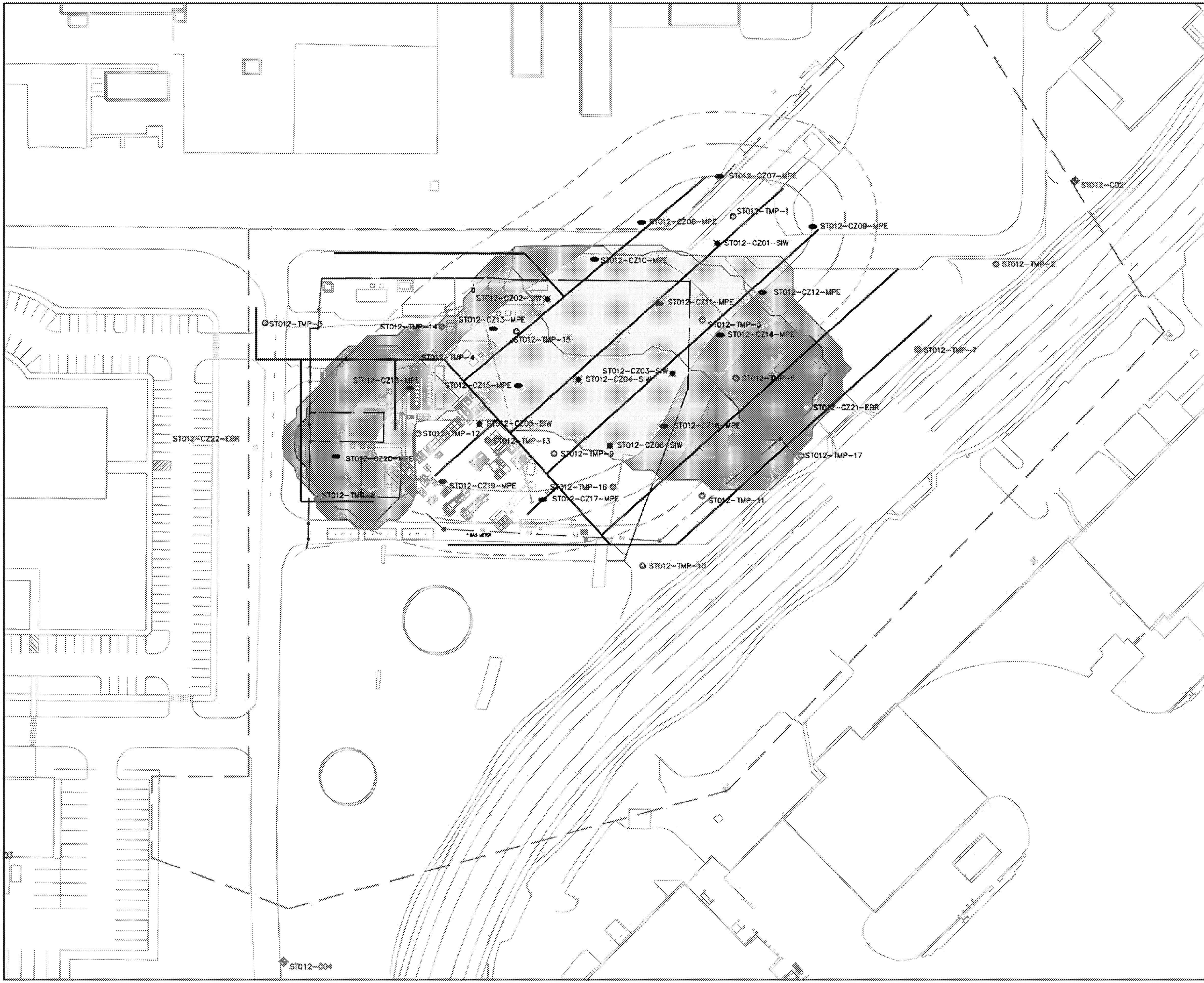
N

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent -
LSZ 220 FT BGS

FIGURE 2-3	
Job No.	9101110001
PM:	EW
Date:	09/28/15
Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW CZ = 6
- MPE CZ = 14
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- CZ RD/RAWP THERMAL TREATMENT ZONE
- PROPOSED INJECTION/SAMPLING LOCATION
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

NOTE: MODEL EXTENT SHADING BASED ON EXPECTED PERCENT REMOVAL WITHIN EACH CONTOUR

Abbreviations

CZ	COBBLE ZONE
LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

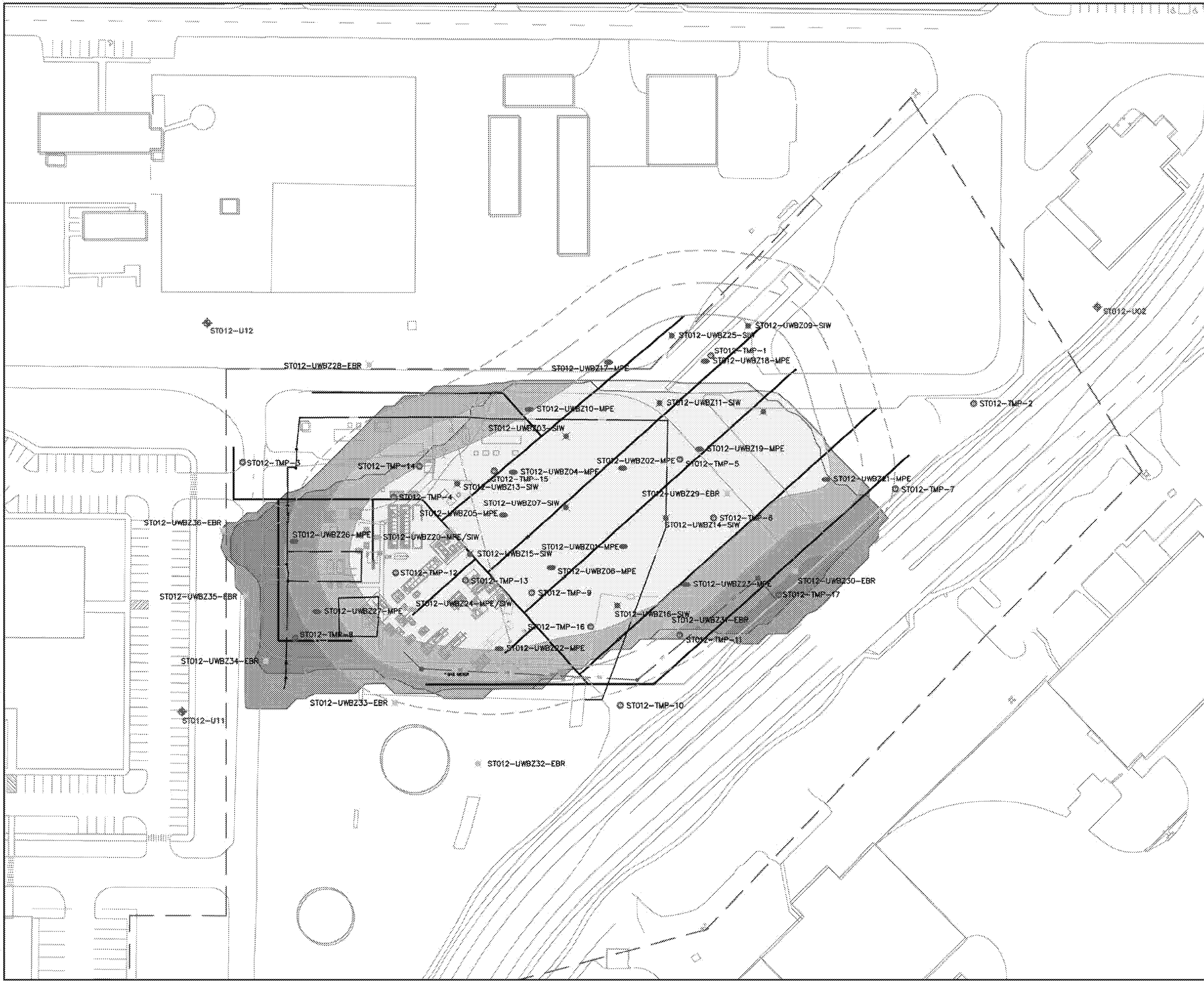
N

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Removal Contours - CZ 160 FT BGS

FIGURE 2-4	
Job No.	9101110001
PM:	EW
Date:	09/28/15
Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW UWBZ = 10
- MPE UWBZ = 14
- DUAL PURPOSE UWBZ = 2
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- UWBZ RD/RAWP THERMAL TREATMENT ZONE
- PROPOSED INJECTION/SAMPLING LOCATION
- W — WATER LINE
- GAS — NATURAL GAS LINE
- S — SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

NOTE: MODEL EXTENT SHADING BASED ON EXPECTED PERCENT REMOVAL WITHIN EACH CONTOUR

Abbreviations

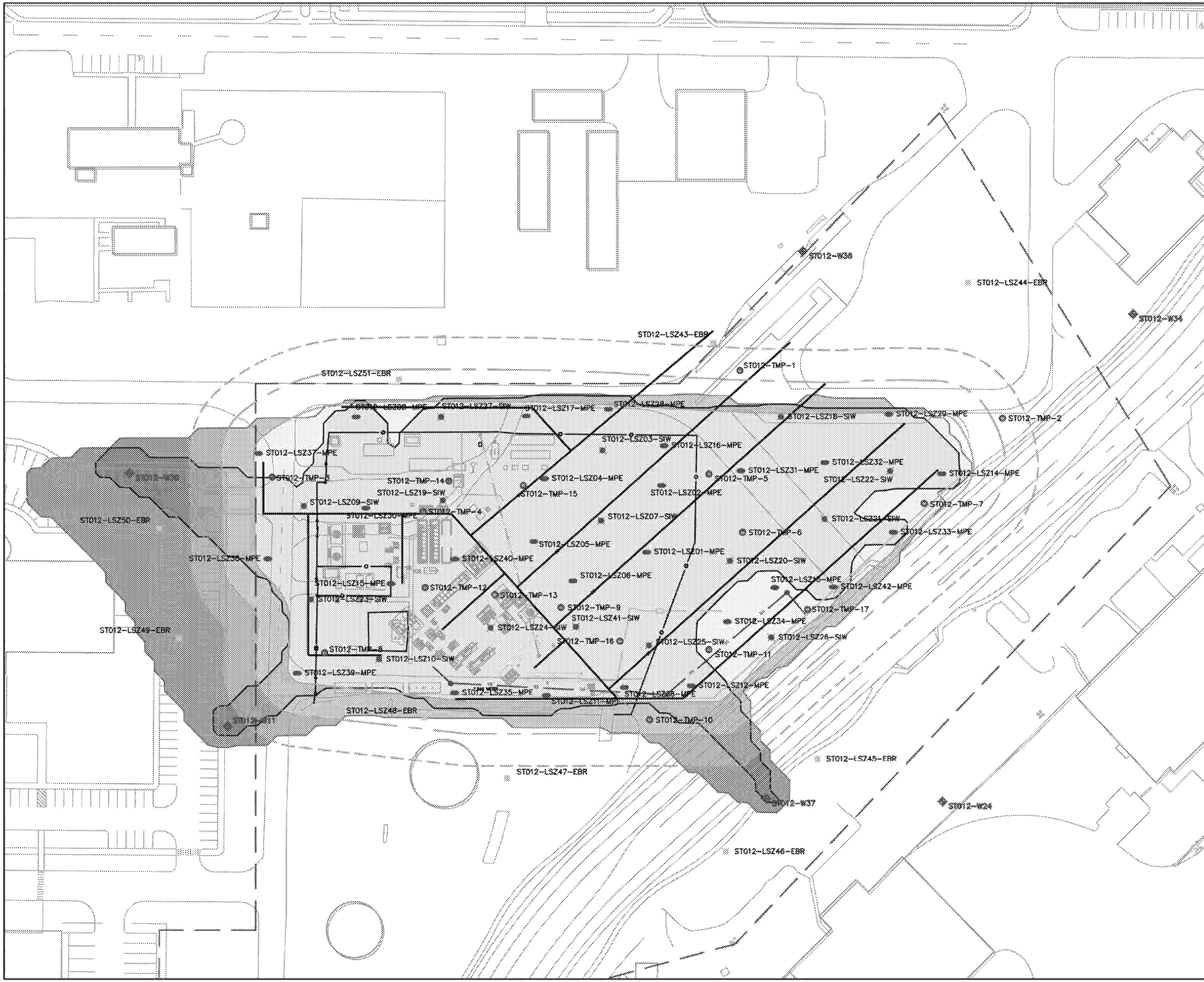
LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT
UWBZ	UPPER WATER BEARING ZONE

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Removal Contours - UWBZ 180 FT BGS

FIGURE 2-5		
	Job No.	9101110001
	PM:	EW
	Date:	09/28/15
	Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW LSZ = 15
- MPE LSZ = 27
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- LSZ RD/RAWP THERMAL TREATMENT ZONE
- PROPOSED INJECTION/SAMPLING LOCATION
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

NOTE: MODEL EXTENT SHADING BASED ON EXPECTED PERCENT REMOVAL WITHIN EACH CONTOUR

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LSZ	LOWER SATURATED ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

N

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Removal Contours - LSZ 220 FT BGS

FIGURE 2-6	
Job No.	9101110001
PM:	EW
Date:	09/28/15
Scale:	1"-100 Feet

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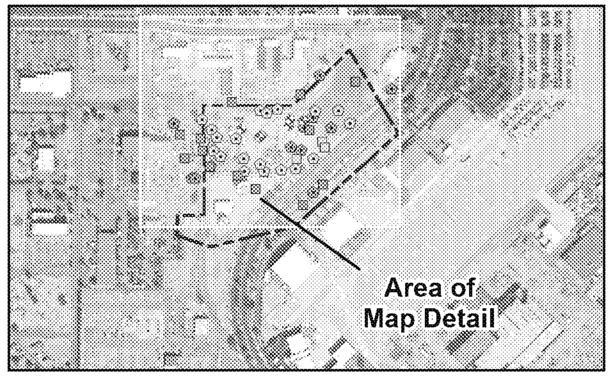

Legend

- Proposed Extraction Well Location
- Proposed Injection Well Location
- Extraction Well Location
- Injection Well Location
- Groundwater Monitoring Well Location
- Fence Line
- ST012 Site Boundary

Notes:

ST012-MW12 Monitoring Well Identification

EBR Enhanced Bioremediation

0 25 50 100 Feet

N

Addendum #2
Remedial Design/Remedial Action
Work Plan
Site ST012 - Former Williams Air Force Base
Mesa, Arizona

EBR Injection, Extraction, and Monitoring Well Locations

FIGURE **3-1**

Job No.:	9101110001
PM:	DS
Date:	11/17/2015
Scale:	1" = 100'

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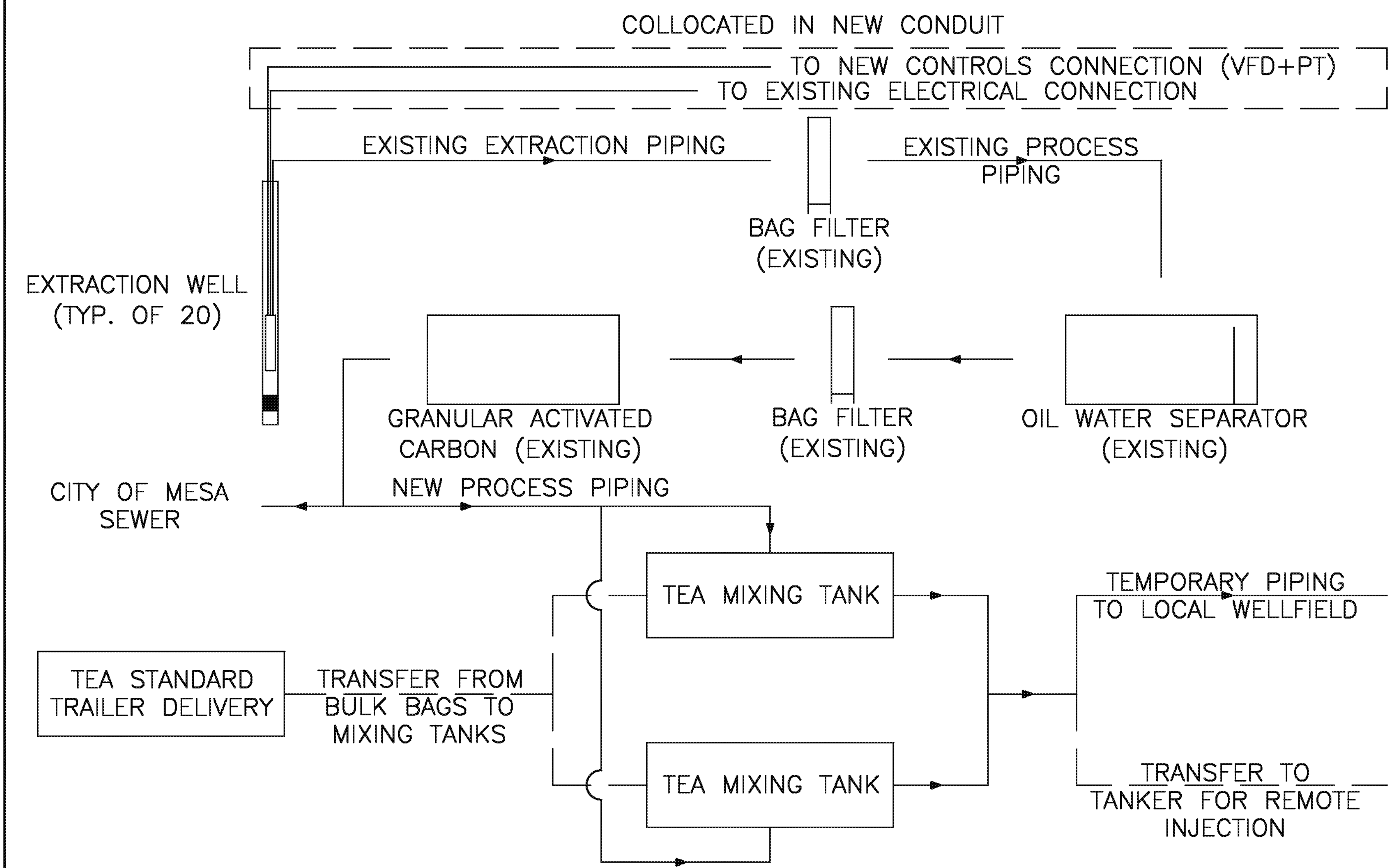

Job No.	9101110001
PM:	EW
Date:	09/28/15
Scale:	1"-100 Feet

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base, Mesa, Arizona

EBR System Process Flow Diagram

FIGURE
3-2

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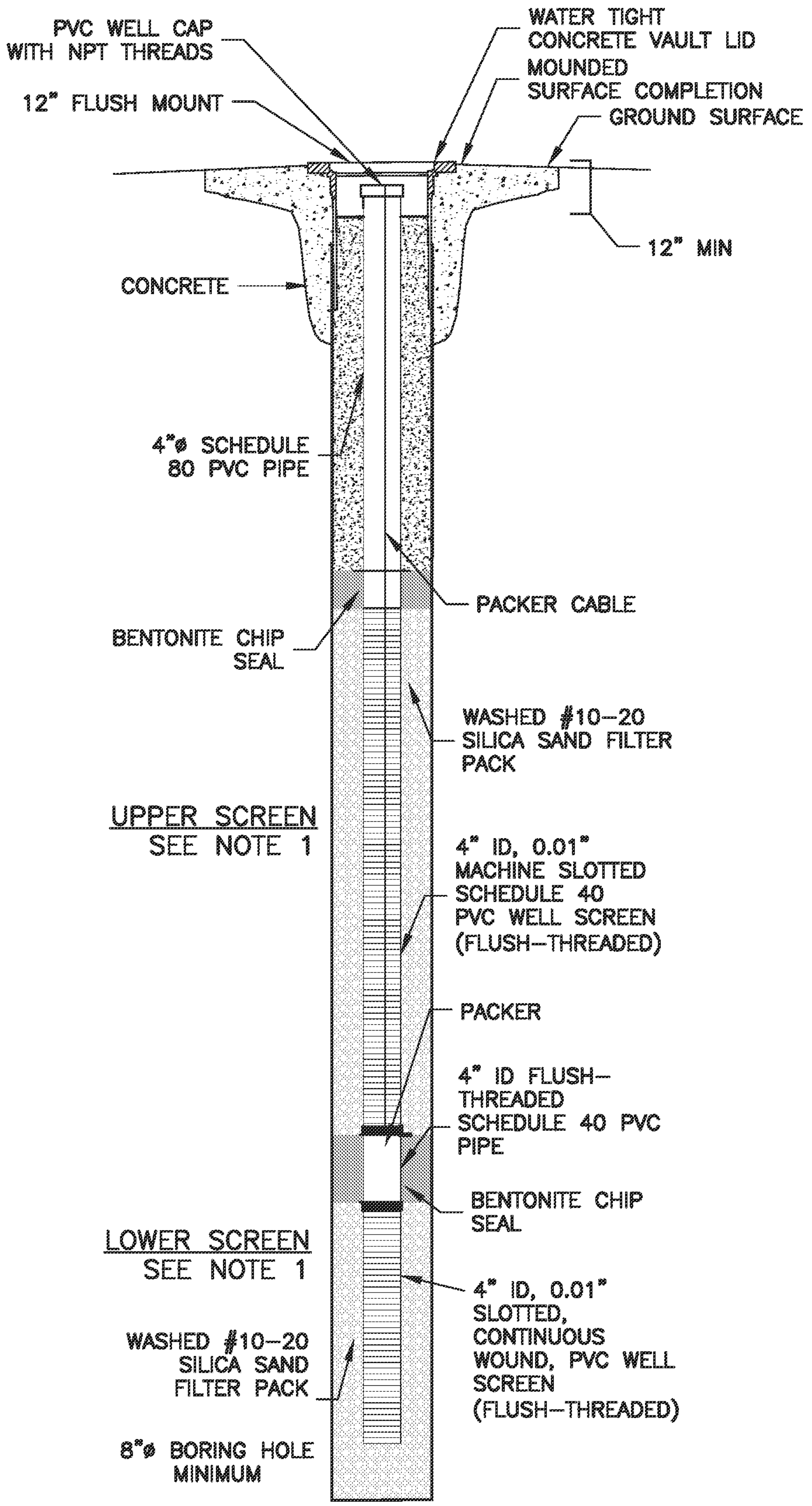
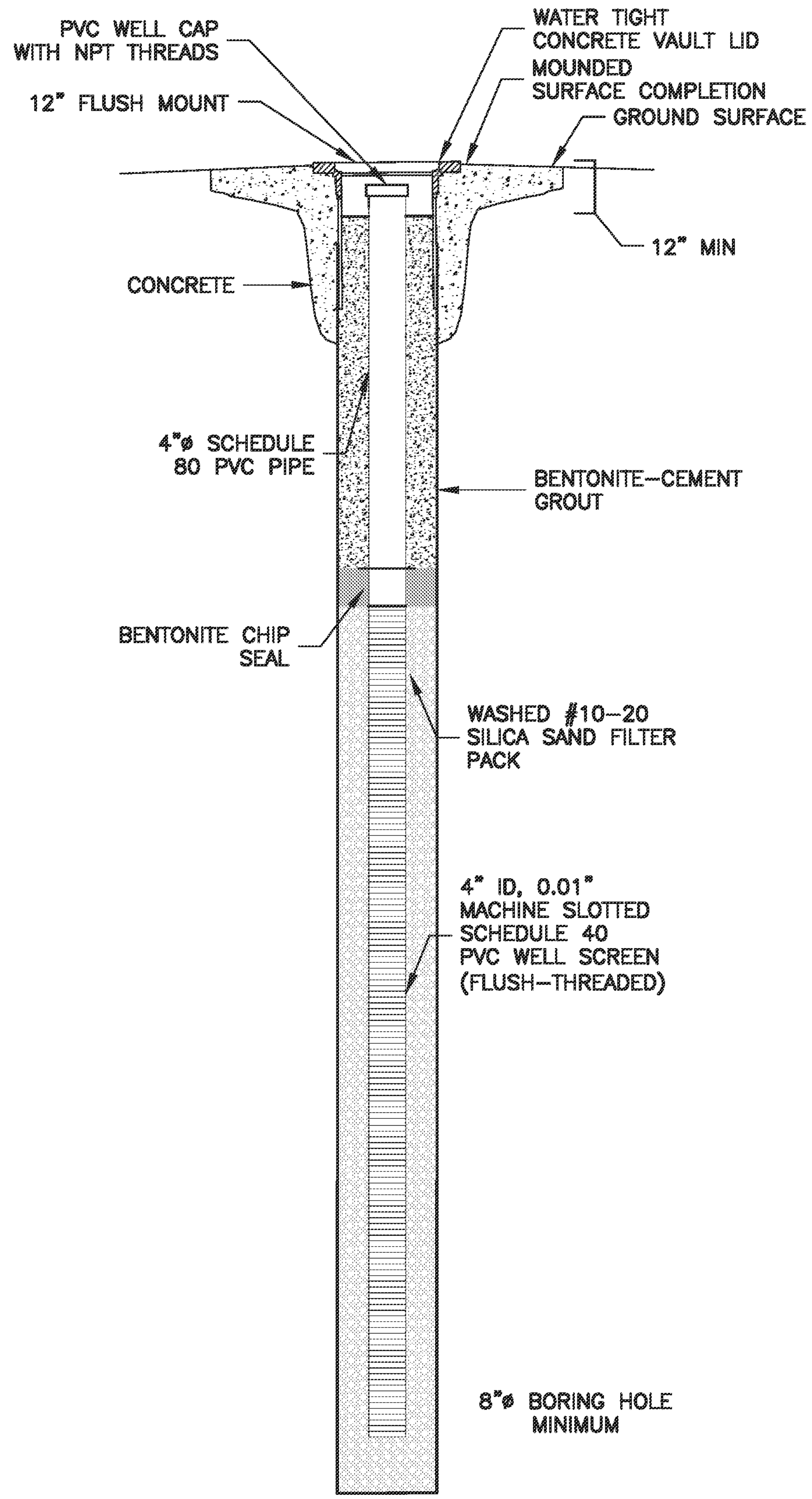


DOUBLE–SCREENED INJECTION WELL

NTS



SINGLE–SCREENED INJECTION
OR EXTRACTION WELL

NTS

NOTE:

1. Screened intervals as specified in Table 4-1.

Abbreviations

- BGS - below ground surface
- ID - inner diameter
- PVC - polyvinyl chloride
- HDPE - high density polyethylene
- NPT - national pipe thread
- NTS - not to scale
- VFD - variable frequency drive
- ' - feet
- Ø - diameter
- " - inches

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Injection and Extraction Well Details

FIGURE 4-1	
Job No.	9101110001
PM:	DS
Date:	09/23/2015
Scale:	NTS

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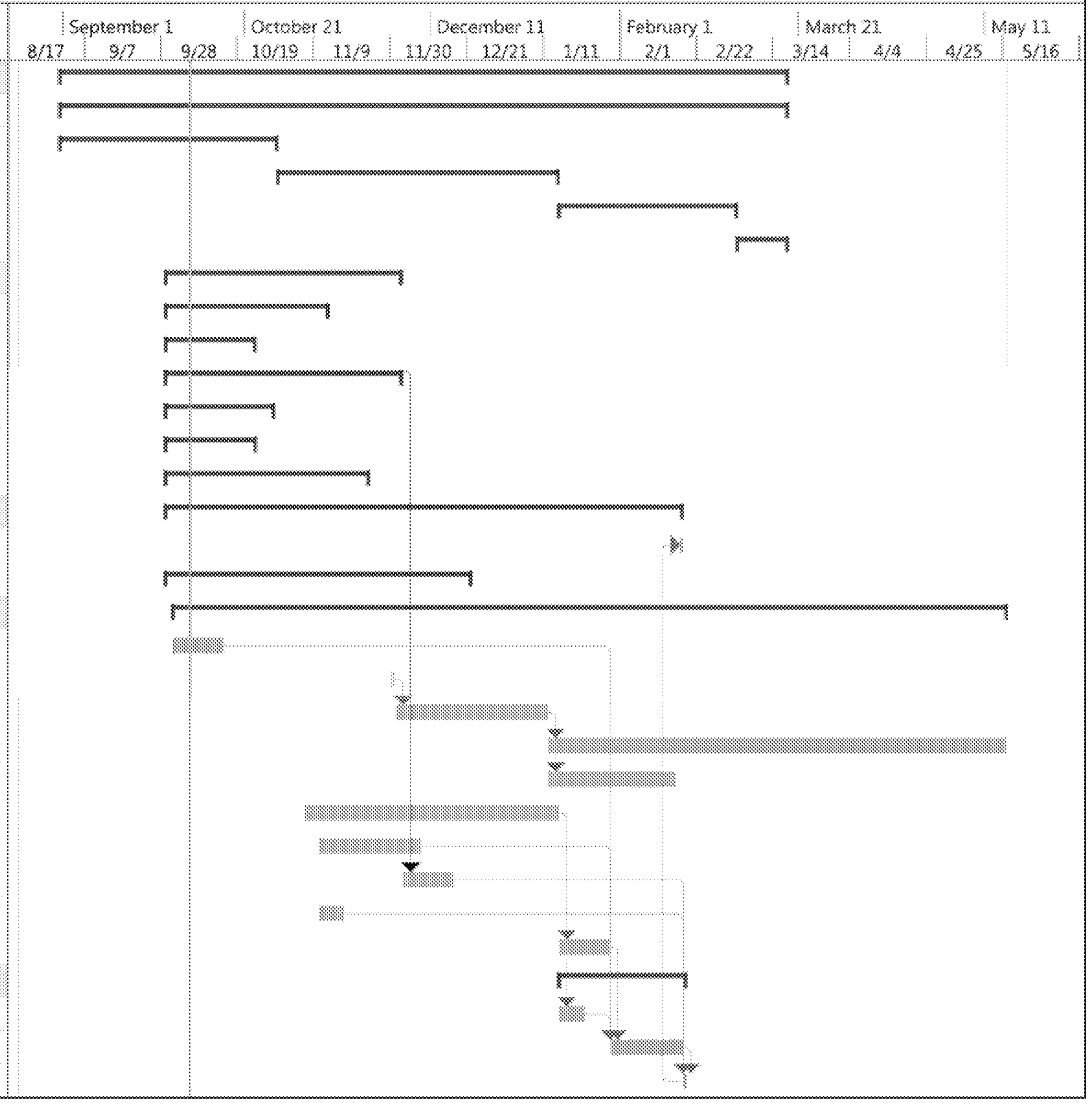
Williams ST012 - EBR Planning and Implementation

ID	Task Name	Duration	Start	Finish
1	**RD/RAWP Addendum**	**144 days**	**Mon 8/31/15**	**Thu 3/17/16**
2	**Addendum Writeup**	**144 days**	**Mon 8/31/15**	**Thu 3/17/16**
3	**Working Copy**	**44 days**	**Mon 8/31/15**	**Thu 10/29/15**
10	**Draft**	**55 days**	**Fri 10/30/15**	**Thu 1/14/16**
13	**Draft Final**	**35 days**	**Fri 1/15/16**	**Thu 3/3/16**
16	**Final**	**10 days**	**Fri 3/4/16**	**Thu 3/17/16**
19	**Procurement**	**47 days**	**Tue 9/29/15**	**Wed 12/2/15**
20	**Drilling**	**33 days**	**Tue 9/29/15**	**Thu 11/12/15**
28	**Terminal Electron Acceptor**	**19 days**	**Tue 9/29/15**	**Fri 10/23/15**
35	**Pumps**	**47 days**	**Tue 9/29/15**	**Wed 12/2/15**
42	**Material Handling Equipment**	**22 days**	**Tue 9/29/15**	**Wed 10/28/15**
49	**Water Treatment Equipment**	**19 days**	**Tue 9/29/15**	**Fri 10/23/15**
56	**Contstruction/Assembly**	**40 days**	**Tue 9/29/15**	**Mon 11/23/15**
64	**Permitting**	**102 days**	**Tue 9/29/15**	**Wed 2/17/16**
65	Register Injection Wells	1 day	Wed 2/17/16	Wed 2/17/16
66	**POTW Discharge**	**60 days**	**Tue 9/29/15**	**Mon 12/21/15**
71	**Construction**	**163 days**	**Thu 10/1/15**	**Mon 5/16/16**
72	Pipelines	10 days	Thu 10/1/15	Wed 10/14/15
73	SEE System Steam Shutdown	1 day	Mon 11/30/15	Mon 11/30/15
74	SEE System Extraction	30 days	Tue 12/1/15	Mon 1/11/16
75	SEE Demolition	90 days	Tue 1/12/16	Mon 5/16/16
76	Open up Cell Phone Lot	25 days	Tue 1/12/16	Mon 2/15/16
77	Drilling & Development	50 days	Fri 11/6/15	Thu 1/14/16
78	Water Treatment	20 days	Tue 11/10/15	Mon 12/7/15
79	TEA Makeup System	10 days	Thu 12/3/15	Wed 12/16/15
80	Chemical Storage Area	5 days	Tue 11/10/15	Mon 11/16/15
81	Pump Installation	10 days	Fri 1/15/16	Thu 1/28/16
82	**EBR Operation**	**25 days**	**Fri 1/15/16**	**Thu 2/18/16**
83	Pre-EBR sampling	5 days	Fri 1/15/16	Thu 1/21/16
84	Start up Extraction	14 days	Fri 1/29/16	Wed 2/17/16
85	Injections Start	1 day	Thu 2/18/16	Thu 2/18/16



Legend

TASK

TASK SUMMARY

Abbreviations

EBR	ENHANCED BIOREMEDIATION
POTW	PUBLICLY OWNED TREATMENT WORKS
RD/RAWP	REMEDIAL DESIGN/REMEDIAL ACTION WORKPLAN
SEE	STEAM ENHANCED EXTRACTION
TEA	TERMINAL ELECTRON ACCEPTOR

DRAFT, ADDENDUM #2
Remedial Design/Remedial Action Work Plan
Site ST012-Former Williams Air Force Base
Mesa, Arizona

Proposed Project Schedule

FIGURE **7-1**

Job No. 9101110001
PM: DS
Date: 09/28/15
Scale: NONE

amec foster wheeler

\\PLD2-FS1\Project\Projects\CADD-PORT\Projects\Williams AFB\ST012 FFS-RD-RA-Work-Plan\EBR Addendum\Figure7-1 - Proposed Project Schedule.dwg Tue, 06 Oct 2015 - 2:02pm john.anderson2

APPENDIX A

2015 MODEL UPDATE CALCULATIONS

Job No.	9101110001	Sheet 1 of 6		
Phase	5200	Task 01		
Job Name	Williams AFB, Site ST012			amec foster wheeler
By	JDA	Date 7/23/15		
Checked By	SCP	Date 10/1/15		511 Congress Street
Revision 1		Date		Portland, ME 04101
Checked By		Date		+1 (207) 775-5401 Fax +1 (207) 772-4762

Purpose: Estimate the volume of residual LNAPL remaining in the thermal treatment zone.

Method:

1 - Estimate volumes of LNAPL contaminated soil in each lithologic unit and within the thermal treatment zone of each lithologic unit .
2 - Calculate pore space volume in each lithologic unit in the thermal treatment zone.
3 - Estimate saturation percentage in each lithologic unit based on TPH analytical data and literature values.
4 - Calculate volume of residual LNAPL.
5 - Estimate the amount of LNAPL that has been removed by previous treatment and natural attenuation.
6 - Calculate the estimated range of remaining residual LNAPL.

Assumptions:

LNAPL contours derived from a review of historical data and the pre-design investigation were used to generate two three dimensional models (in TecPlot) representing a range of volume of soil on site. The smaller volume represents the areas with strong indication of LNAPL presence through recent data (PDI soil testing, well borings from recent remedial action implementation, recent measureable LNAPL in wells, and supported by high dissolved phase groundwater concentrations). This volume represents the volume likely to be contributing the most to dissolve phase concentrations above cleanup levels. The second, more conservative volume represents areas that may have been exposed to LNAPL at some point in the site history, but may not currently have free-phase product or high groundwater concentrations.

The same review was also used to review soil classification data and model the divisions between lithologic units. The TecPlot model was used to determine the volume of LNAPL contaminated soils within each unit and within the thermal treatment zone.

Porosity of 0.3 for all lithologic units was used to maintain consistency with the Terratherm design assumptions.

Applied NAPL Science Review, Volume 2, Issue 1, January 2012, LCCM Tools: Conversion of TPH in Soils to NAPL Saturation, gives a relationship between TPH and NAPL saturation as follows:

$$S_n = \text{TPH} \cdot \frac{(1-\phi)\cdot \text{Grain Density} \cdot 10^{-6}}{\phi\rho} \quad \text{where } \phi = \text{porosity, and } \rho = \text{LNAPL density}$$

where:

S_n	= natural saturation (dimensionless)
TPH	= soil total petroleum hydrocarbon contamination (mg/kg)
Φ	= soil porosity
ρ	= LNAPL density g/cm^3

and grain density is in g/cm^3

Literature values identified in previous BEM modeling efforts for LNAPL saturation of different soil types are also assumed to be valid.

LNAPL is assumed to be at residual saturation. Although some LNAPL accumulates in monitoring wells indicating mobile LNAPL above residual saturation, a condition of residual saturation is likely present for most of the area.

Previous contaminant removal quantities are summarized and sourced in the 2012 FFS, Section 3.4. Only methods impacting soils in the thermal treatment zones were included (the SVE systems were not screened deeply enough to impact the soils in question, and so were not included in the calculation).

In some instances, adjacent soil samples provided analytical results ranging from high concentrations to non-detect and not all borings within the interpreted distribution of LNAPL show strong indicators of LNAPL presence; this suggests that LNAPL distribution is not uniform across the estimated volume of LNAPL contaminated soils an(LNAPL volumes estimated assuming uniform distribution of LNAPL within the area may over estimate actual LNAPL volume. . Assumed factors are applied to develop a range to reflect this condition although there is no reliable data to quantitatively estimate this factor.

Constants and Inputs:

2.65	g/cm^3	grain density
0.3	-	total porosity
0.7787	g/cm^3	LNAPL specific gravity (ranges from 0.75 to 0.80 for JP-4)
1%	-	cobble zone LNAPL saturation (no literature value was found matching the cobble zone soil type; an engineer's estimate of 1% was used for the associated LNAPL calculations)
75%	-	assumed low end factor of percent of interpreted LNAPL area actually impacted by LNAPL

Job No.	9101110001	Sheet 2 of 6		
Phase	5200	Task 01		
Job Name	Williams AFB, Site ST012			
By	JDA	Date 7/23/15		
Checked By	SCP	Date 10/1/15	511 Congress Street	
Revision 1		Date	Portland, ME 04101	
Checked By		Date	+1 (207) 775-5401 Fax +1 (207) 772-4762	

References:

Hawthorne, J. M. & Kirkman, A. J. (2012). LCCM Tools: Conversion of TPH in Soils to NAPL Saturation*Applied NAPL Science Review, 2*(1).

BEM, 2010, *Final Construction Completion/Inspection Report, Former Williams Air Force Base, Arizona*, prepared for Air Force Center for Engineering and the Environment, Lackland AFB, Texas, May 2010.

AMEC, 2012, *Final Focused Feasibility Study, Remedial Alternatives for Operable Unit 2, Site ST012, Former Williams Air Force Base, Mesa, Arizona*, prepared for the Air Force Civil Engineer Center (AFCEC), Lackland Air Force Base, Texas, November

Feenstra et al., 1991. A Method for Assessing Residual NAPL Based on Organic Chemical Concentrations in Soil Samples. *Groundwater Monitoring & Remediation*, 11, 128 – 135

Calculations:

1 - Estimate volumes of LNAPL contaminated soil in each lithologic unit and within the thermal treatment zone of each lithologic unit .

A. Interpret vertical distribution of LNAPL in individual borings for pre-design investigation locations and historical borings (where available)

The following parameters were used based on observations/data for borings for the LNAPL scoring system:

1. If there was a positive dye test within the interval, the interval was automatically scored "Likely Residual LNAPL"
2. If the analytical results for Benzene, Toluene, Ethylbenzene, and Total Xylenes (BTEX) or Naphthalene within the interval showed concentrations indicative of LNAPL based on the methods in Feenstra, et al, 1991, then that interval was automatically scored as "Likely Residual LNAPL"
3. If neither dye test kit results nor BTEX/Naphthalene analytical results indicated the presence of LNAPL or if data was unavailable, the following scoring was used:

Staining:	0 - None, no evidence of LNAPL
	1 - Minimal staining, weak evidence of LNAPL
	2 - Staining or dark staining, strong evidence of LNAPL
Odor:	0 - None, no evidence of LNAPL
	1 - Slight/very slight odor, weak evidence of LNAPL
	2 - Odor, or strong/very strong odor, strong evidence of LNAPL
Dye Test:	0 - None
	4 - LNAPL present
PID:	0 - <45 ppmv, no evidence of LNAPL
	1 - between 45 and 450 ppmv, weak evidence of LNAPL
	2 - > 450 ppmv, strong evidence of LNAPL
Benzene:	0 - less than 20 mg/kg, no evidence of LNAPL
	1 - between 20 and 200 mg/kg, weak evidence of LNAPL
	2 - > 200 mg/kg, strong evidence of LNAPL
TPH (JP-4)	0 - less than 25 mg/kg, no evidence of LNAPL
	1 - between 25 and 250 mg/kg, weak evidence of LNAPL
	2 - > 250 mg/kg, strong evidence of LNAPL

Interpretations were made on 1-foot vertical intervals. Where data for a given parameter was available less frequently, the score from the closest location above was carried down unless there was a technical basis to do otherwise (e.g., significant change in lithologic unit, maximum depth of historical water table)

The score from all of the factors were sumed for each 1-foot interval. Summed values of 6 and greater were considered vertical intervals where current or historical LNAPL presence was likely.

B. Interpretation of LNAPL data to develop LNAPL volumes.

To interpret the extent of LNAPL, the scores for the individual 1-foot intervals were summed for 10-foot intervals. The extent of LNAPL was then contoured manually for each 10-foot interval. Two different interpretations of LNAPL extent were made with the manual contouring. The first interpretation focused on scores greater than 30 on recent data from the Pre-Design Investigation borings and well borings from remedial action implementation, additionally informed by areas of measured LNAPL in monitoring wells and with consideration of whether LNAPL presence is supported by dissolved phase concentrations. This second, more conservative interpretation considered scores greater than 20 for a 10-foot interval representative of LNAPL presence and considered both historical and Pre-Design Investigation locations. Contours were extended to include monitoring wells known to have observed LNAPL but lack additional evidence of LNAPL (e.g. boring logs not available). The individual 10-foot contours were entered into the TecPlot model. Figures in Appendix B represent the estimated extent of LNAPL under these two interpretations. The figures in Appendix B show the TTZ and EBR treatment zones relative to the LNAPL interpretation footprints for the CZ, UWBZ, and LSZ respectively.

The Tecplot model was used to determine the volume of LNAPL saturated soils within the lithologic units at the site and within the thermal treatment zones (TTZs).

	LNAPL Volume Interpretation		Conservative LNAPL Volume Interpretation	
	Total Volume (cu ft)	Volume within TTZ (cu ft)	Total Volume (cu ft)	Volume within TTZ (cu ft)
CZ	343,000	256,000	681,000	478,750
UWBZ	3,223,500	1,834,500	4,698,500	2,696,500
LPZ*	2,263,500	1,683,075	2,717,500	1,844,100
LSZ	4,695,489	4,193,991	7,378,000	5,616,250

*75 cu ft per LPZ cell, 250 cu ft for all other zones

Job No.	9101110001	Sheet	3	of	6
Phase	5200	Task	01		
Job Name	Williams AFB, Site ST012				
By	JDA	Date	7/23/15		
Checked By	SCP	Date	10/1/15		
Revision 1		Date			
Checked By		Date			

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2 - Calculate pore space volume in each lithologic unit in the thermal treatment zone.

A porosity of 0.3 was used for all lithologic units to remain consistent with the SEE design.

	LNAPL Volume Interpretation		Conservative LNAPL Volume	
	Total Pore Space (cu ft)	Pore Space within TTZ (cu	Total Pore Space (cu ft)	Pore Space within TTZ (cu ft)
CZ	102,900	76,800	204,300	143,625
UWBZ	967,050	550,350	1,409,550	808,950
LPZ	679,050	504,923	815,250	553,230
LSZ	1,408,647	1,258,197	2,213,400	1,684,875

3 - Estimate saturation percentage in each lithologic unit based on TPH analytical data from PDI and RA well installation and literature values. Observed concentrations calculated by generating an average of multiple sampling locations within each vertical zone for each well to compare with remedial action analytical data.

	Grain Density (g/cc)	LNAPL Density (g/cc)	Average Observed Concentration TPH (mg/kg)	Calculated LNAPL Saturation	Literature Value LNAPL Saturation
CZ	2.65	0.7787	1,760	1.40%	1.00%
UWBZ	2.65	0.7787	4,919	3.91%	4.10%
LPZ	2.65	0.7787	3,565	2.83%	2.80%
LSZ	2.65	0.7787	3,047	2.42%	5.80%

4 - Calculate volume of residual LNAPL.

Total Residual Volume - LNAPL Volume Interpretation

	Total Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	102,900	1.40%	1,438	1.00%	1,029
UWBZ	967,050	3.91%	37,773	4.10%	39,649
LPZ	679,050	2.83%	19,223	2.80%	19,013
LSZ	1,408,647	2.42%	34,082	5.80%	81,702
Total	3,157,647		92,516		141,393

Residual Volume within TTZs - LNAPL Volume Interpretation

	Treatment Area Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	76,800	1.40%	1,073	1.00%	768
UWBZ	550,350	3.91%	21,497	4.10%	22,564
LPZ	504,923	2.83%	14,293	2.80%	14,138
LSZ	1,258,197	2.42%	30,442	5.80%	72,975
Total	2,390,270		67,305		110,446

Total Residual Volume - Conservative LNAPL Volume Interpretation

	Total Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	204,300	1.40%	2,855	1.00%	2,043
UWBZ	1,409,550	3.91%	55,057	4.10%	57,792
LPZ	815,250	2.83%	23,078	2.80%	22,827
LSZ	2,213,400	2.42%	53,553	5.80%	128,377
Total	4,642,500		134,543		211,039

Job No.	9101110001	Sheet	4 of 6		
Phase	5200	Task	01		
Job Name	Williams AFB, Site ST012				
By	JDA	Date	7/23/15		
Checked By	SCP	Date	10/1/15		
Revision 1		Date			
Checked By		Date			

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Residual Volume within TTZs - Conservative LNAPL Volume Interpretation

	Treatment Area Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	143,625	1.40%	2,007	1.00%	1,436
UWBZ	808,950	3.91%	31,597	4.10%	33,167
LPZ	553,230	2.83%	15,661	2.80%	15,490
LSZ	1,684,875	2.42%	40,765	5.80%	97,723
Total	3,190,680		90,031		147,816

5 - Estimate the amount of LNAPL that has been removed by pre-SEE treatment and natural attenuation.
See FFS (AMEC, 2012) for basis/references.

	UWBZ (gallons)	LSZ (gallons)	Total (gallons)	
TEE Pilot	9,070	9,070	18,140	(assumed roughly equal in each zone)
Biodegradation	997	4,986	5,980	(100 % LSZ from 1969-1997, then 50/50)
Skimming/Bioslurping	0	10,564	10,564	(primarily removed from LSZ)
Total	10,067	24,620	34,684	

Note: Additional LNAPL mass has been removed from the CZ by the deep soil SVE system but has not been quantified specific to this zone and has not been included in the historical removal estimate.

6 - Calculate the estimated range of pre-SEE treatment remaining residual LNAPL.

An assumed uncertainty factor applied to account for LNAPL distribution being through lenses and strigers rather than continuous throughout the zone. This provides a lower range estimate of volumes. NAPL removal is only applied to volumes using literature residual saturation because calculated residuals already account for NAPL removal via the average TPH values.

Uncertainty factor for treatment volume: 75%
Uncertainty factor for EBR volume: 50%

LNAPL Interpretation

		EBR Treatment Area Volume		Treatment Area Volume		Total Residual Volume	
Vertical Zone	**NAPL Parameter**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**
Cobble Zone	cu ft	365	261	1,073	768	1,438	1,029
	gallons	2,728	1,952	8,028	5,745	10,757	7,697
	NAPL Removed (gallons)	0	0	0	0	0	0
	Remaining NAPL (gallons)	2,728	1,952	8,028	5,745	10,757	7,697
	Uncertainty Factor	50%	50%	75%	75%	69%	69%
	Lower Range (gallons)	1,364	976	6,021	4,308	7,385	5,285
Upper Water Bearing Zone	cu ft	16,276	17,085	21,497	22,564	37,773	39,649
	gallons	121,746	127,794	160,794	168,781	282,540	296,575
	NAPL Removed (gallons)	0	0	0	10,067	0	10,067
	Remaining NAPL (gallons)	121,746	127,794	160,794	158,714	282,540	286,508
	Uncertainty Factor	50%	50%	75%	75%	64%	64%
	Lower Range (gallons)	60,873	63,897	120,596	119,036	181,468	182,932
Low Permeability Zone	cu ft	4,929	4,876	14,293	14,138	19,223	19,013
	gallons	36,871	36,469	106,915	105,751	143,786	142,220
	NAPL Removed (gallons)	0	0	0	0	0	0
	Remaining NAPL (gallons)	36,871	36,469	106,915	105,751	143,786	142,220
	Uncertainty Factor	50%	50%	75%	75%	69%	69%
	Lower Range (gallons)	18,435	18,235	80,186	79,313	98,622	97,548
Lower Saturated Zone	cu ft	3,640	8,726	30,442	72,975	34,082	81,702
	gallons	27,228	65,271	227,706	545,856	254,935	611,127
	NAPL Removed (gallons)	0	0	0	24,620	0	24,620
	Remaining NAPL (gallons)	27,228	65,271	227,706	521,236	254,935	586,507
	Uncertainty Factor	50%	50%	75%	75%	72%	72%
	Lower Range (gallons)	13,614	32,635	170,780	390,927	184,394	423,563

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Vertical Zone	NAPL Parameter	EBR Treatment Area Volume		Treatment Area Volume		Total Residual Volume	
		Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL
Cobble Zone and Upper Water Bearing Zone Thermal Treatment Zone	cu ft	19,106	19,783	29,717	30,401	48,822	50,185
	gallons	142,910	147,980	222,280	227,401	365,190	375,382
	NAPL Removed (gallons)	0	0	10,067	10,067	10,067	10,067
	Remaining NAPL (gallons)	142,910	147,980	212,213	217,334	355,122	365,315
	Uncertainty Factor	50%	50%	75%	75%	65%	65%
	Lower Range (gallons)	71,455	73,990	159,159	163,001	230,614	236,991
Lower Saturated Zone Thermal Treatment Zone	cu ft	6,105	11,164	37,589	80,044	43,693	91,208
	gallons	45,663	83,506	281,164	598,732	326,827	682,237
	NAPL Removed (gallons)	0	0	24,620	24,620	24,620	24,620
	Remaining NAPL (gallons)	45,663	83,506	256,544	574,112	302,207	657,617
	Uncertainty Factor	50%	50%	75%	75%	71%	72%
	Lower Range (gallons)	22,832	41,753	192,408	430,584	215,240	472,337
Cobble Zone, Upper Water Bearing Zone, Low Permeability Zone, and Lower Saturated Zone	cu ft	25,210	30,947	67,305	110,446	92,516	141,393
	gallons	188,573	231,486	503,444	826,133	692,017	1,057,619
	NAPL Removed (gallons)	0	0	34,687	34,687	34,687	34,687
	Remaining NAPL (gallons)	188,573	231,486	468,756	791,446	657,329	1,022,932
	Uncertainty Factor	50%	50%	75%	75%	68%	69%
	Lower Range (gallons)	94,287	115,743	351,567	593,584	445,854	709,327

Conservative LNAPL Interpretation

	TTZ	EBR Treatment Area Volume		Treatment Area Volume		Total Residual Volume	
		Calculated Volume of	Volume of LNAPL	Calculated Volume of	Volume of LNAPL	Volume of LNAPL	Volume of LNAPL
Cobble Zone	cu ft	848	607	2,007	1,436	2,855	2,043
	gallons	6,343	4,538	15,014	10,743	21,357	15,282
	NAPL Removed (gallons)	0	0	0	0	0	0
	Remaining NAPL (gallons)	6,343	4,538	15,014	10,743	21,357	15,282
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	3,171	2,269	11,261	8,057	16,018	11,461
Upper Water Bearing Zone	cu ft	23,459	24,625	31,597	33,167	55,057	57,792
	gallons	175,475	184,192	236,348	248,089	411,824	432,281
	NAPL Removed (gallons)	0	0	10,067	10,067	10,067	10,067
	Remaining NAPL (gallons)	175,475	184,192	226,281	238,022	401,757	422,214
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	87,738	92,096	169,711	178,516	301,317	316,660
Low Permeability Zone	cu ft	7,417	7,337	15,661	15,490	23,078	22,827
	gallons	55,481	54,877	117,144	115,868	172,625	170,746
	NAPL Removed (gallons)	0	0	0	0	0	0
	Remaining NAPL (gallons)	55,481	54,877	117,144	115,868	172,625	170,746
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	27,741	27,439	87,858	86,901	129,469	128,059
Lower Saturated Zone	cu ft	12,788	30,654	40,765	97,723	53,553	128,377
	gallons	95,652	229,295	304,926	730,966	400,577	960,261
	NAPL Removed (gallons)	0	0	24,620	24,620	24,620	24,620
	Remaining NAPL (gallons)	95,652	229,295	280,306	706,346	375,957	935,641
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	47,826	114,648	210,229	529,760	281,968	701,731

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		EBR Treatment Area Volume		Treatment Area Volume		Total Residual Volume	
Vertical Zone	NAPL Parameter	Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL
Cobble Zone and Upper Water Bearing Zone Thermal Treatment Zone	cu ft	28,016	28,900	41,435	42,348	69,451	71,248
	gallons	209,559	216,169	309,934	316,766	519,493	532,935
	NAPL Removed (gallons)	0	0	10,067	10,067	10,067	10,067
	Remaining NAPL (gallons)	209,559	216,169	299,867	306,699	509,426	522,868
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	104,779	108,085	224,900	230,024	382,069	392,151
Lower Saturated Zone Thermal Treatment Zone	cu ft	16,496	34,323	48,596	105,468	65,092	139,791
	gallons	123,392	256,734	363,498	788,900	486,890	1,045,634
	NAPL Removed (gallons)	0	0	24,620	24,620	24,620	24,620
	Remaining NAPL (gallons)	123,392	256,734	338,878	764,280	462,270	1,021,014
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	61,696	128,367	254,158	573,210	346,702	765,761
Cobble Zone, Upper Water Bearing Zone, Low Permeability Zone, and Lower Saturated Zone	cu ft	44,512	63,222	90,031	147,816	134,543	211,039
	gallons	332,951	472,903	673,432	1,105,667	1,006,383	1,578,570
	NAPL Removed (gallons)	0	0	34,687	34,687	34,687	34,687
	Remaining NAPL (gallons)	332,951	472,903	638,745	1,070,979	971,696	1,543,882
	Uncertainty Factor	50%	50%	75%	75%	75%	75%
	Lower Range (gallons)	166,476	236,452	479,058	803,234	728,772	1,157,912

Conclusion:

Using the literature values that BEM used in previous site modeling during the TEE pilot test and the new interpretations of LNAPL extent, the amount of LNAPL in the thermal treatment zones is estimated to be between 590,000 and 790,000 (base interpretation) or 800,000 and 1,070,000 gallons (conservative LNAPL interpretation), leaving between 120,000 and 230,000 (base interpretation) or 240,000 and 470,000 gallons (conservative LNAPL interpretation) in the area outside the thermal treatment zones.

Using the concentrations of TPH in the soil and the equation developed by Hawthorne and Kirkman, the amount of NAPL in the thermal treatment zone is estimated to be between 350,000 and 470,000 (base interpretation) or 480,000 and 640,000 gallons (conservative LNAPL interpretation), leaving between 90,000 and 190,000 (base interpretation) 170,000 and 330,000 gallons (conservative LNAPL interpretation) in the area outside the treatment zone.

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Purpose: Estimate the volume of residual LNAPL remaining at the Site following SEE treatment.

Method:
1 - Estimate volumes of LNAPL contaminated soil in each lithologic unit and within the thermal treatment zone (TTZ) of each lithologic unit .
2 - Calculate pore space volume in each lithologic unit in the TTZ.
3 - Estimate saturation percentage in each lithologic unit based on TPH analytical data and literature values.
4 - Calculate volume of residual LNAPL.
5 - Estimate the amount of LNAPL that has been removed by previous treatment and natural attenuation.
6 - Calculate the estimated range of remaining residual LNAPL following SEE.

Assumptions:

LNAPL contours derived from a review of historical data and the pre-design investigation were used to generate two three dimensional models (in TecPlot) representing a range of volume of soil on site. The smaller volume represents the areas with strong indication of LNAPL presence through recent data (PDI soil testing, well borings from recent remedial action implementation, recent measureable LNAPL in wells, and supported by high dissolved phase groundwater concentrations). This volume represents the volume likely to be contributing the most to dissolve phase concentrations above cleanup levels. The second, more conservative volume represents areas that may have been exposed to LNAPL at some point in the site history, but may not currently have free-phase product or high groundwater concentrations.

The same review was also used to review soil classification data and model the divisions between lithologic units. The TecPlot model was used to determine the volume of LNAPL contaminated soils within each unit and within the thermal treatment zone.

Porosity of 0.3 for all lithologic units was used to maintain consistency with the TIZ design assumptions.

Applied NAPL Science Review, Volume 2, Issue 1, January 2012, LCCM Tools: Conversion of TPH in Soils to NAPL Saturation, gives a relationship between TPH and NAPL saturation as follows:

$$S_n = TPH \cdot \frac{(1-\phi)\cdot \text{Grain Density}\cdot 10^{-6}}{\phi\rho} \quad \text{where } \phi = \text{porosity, and } \rho = \text{LNAPL density}$$

where:
S_n = natural saturation (dimensionless)
TPH = soil total petroleum hydrocarbon contamination (mg/kg)
Φ = soil porosity
ρ = LNAPL density g/cm^3
and grain density is in g/cm^3

Literature values identified in previous BEM modeling efforts for LNAPL saturation of different soil types are also assumed to be valid.

LNAPL is assumed to be at residual saturation. Although some LNAPL accumulates in monitoring wells indicating mobile LNAPL above residual saturation, a condition of residual saturation is likely present for most of the area.

Previous contaminant removal quantities are summarized and sourced in the 2012 FFS, Section 3.4. Only methods impacting soils in the thermal treatment zones were included (the SVE systems were not screened deeply enough to impact the soils in question, and so were not included in the calculation.

In some instances, adjacent soil samples provided analytical results ranging from high concentrations to non-detect and not all borings within the interpreted distribution of LNAPL show strong indicators of LNAPL presence; this suggests that LNAPL distribution is not uniform across the estimated volume of LNAPL contaminated soils and LNAPL volumes estimated assuming uniform distribution of LNAPL within the area may over estimate actual LNAPL volume. . Assumed factors are applied to develop a range to reflect this condition although there is no reliable data to quantitatively estimate this factor.

Assumptions for SEE Treatment by Contour and Zone
The implementation of the SEE system at the site focused treatment on the TTZ for the CZ, UWBZ, and LSZ. The operator indicated that they expected heating (thermal influence zone [TIZ]) to a distance of 10 meters beyond the boundary of the TTZ based on previous experience. The radius of influence of the perimeter extraction wells of the SEE system is expected to extend beyond both the boundary of the TTZ and the TIZ boundary. A distance of 10 meters (20 meters outside of each TTZ) was estimated for the extended radius of influence.

SEE Treatment in the CZ, UWBZ, and LSZ will be assumed to follow the following reductions based on the modeled locations of the TTZ, TIZ and ROI contours. Treatment in the LPZ will be assumed to follow the UWBZ contours on the upper half and LSZ contours on the bottom half of the zone. All LPZ treatment will be assumed the same percentage.

	TTZ	TIZ	ROI	LPZ
% Reduction	90%	60%	30%	30%

Treatment in the LPZ broken down between the UWBZ contours and the LSZ contours. The top half of the LPZ (195 - 202.5 ft bgs) was assumed to be contained in the UWBZ contours, whereas treatment of the bottom half (202.5 - 210 ft bgs) is assumed to be contained within the LSZ contours.

Assumed volatile fraction reduction in each SEE treatment area. The increase in temperature in the TTZ and TIZ is likely to cause a preferential volatilization of ligh VOCs including benzene. To account for this volatilization, the following volatilization reduction factors were applied to final mass estimates.

	TTZ	TIZ	ROI	Untreated
Volatilization Reduction Factor	90%	25%	0%	0%

Constants and Inputs:

2.65	g/cm^3	grain density
0.3	-	total porosity
0.7787	g/cm^3	LNAPL specific gravity (ranges from 0.75 to 0.80 for JP-4)
1%	-	cobble zone LNAPL saturation (no literature value was found matching the cobble zone soil type; an engineer's estimate of 1% was used for the associated LNAPL calculations)

Assumed low end factor of percent of interpreted LNAPL area actually impacted by LNAPL is broken out by treatment zone:

	TTZ	TIZ	ROI	Untreated EBR
Uncertainty Factor	75%	65%	55%	50%

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References: Hawthorne, J. M. & Kirkman, A. J. (2012). LCCM Tools: Conversion of TPH in Soils to NAPL Saturation. *Applied NAPL Science Review, 2*(1).
BEM, 2010, *Final Construction Completion/Inspection Report, Former Williams Air Force Base, Arizona* prepared for Air Force Center for Engineering and the Environment, Lackland AFB, Texas, May 2010.
AMEC, 2012, *Final Focused Feasibility Study, Remedial Alternatives for Operable Unit 2, Site ST012, Former Williams Air Force Base, Mesa, Arizona* prepared for the Air Force Civil Engineer Center (AFCEC), Lackland Air Force Base, Texas, November 2012. [AR# 1535]
Feenstra et al., 1991. A Method for Assessing Residual NAPL Based on Organic Chemical Concentrations in Soil Samples. *Groundwater Monitoring & Remediation*, 11, 128 – 135

Calculations: **1 - Estimate volumes of LNAPL contaminated soil in each lithologic unit and within the thermal treatment zone, 10 meters outside of the thermal treatment**

A. Interpret vertical distribution of LNAPL in individual borings for pre-design investigation locations and historical borings (where available)
The following scoring interpretations were used based on observations/data for borings:

1. If there was a positive dye test within the interval, the interval was automatically scored "Likely Residual LNAPL"
2. If the analytical results for Benzene, Toluene, Ethylbenzene, and Total Xylenes (BTEX) or Naphthalene within the interval showed concentrations indicative of LNAPL based on the methods in Feenstra, et al, 1991, then that interval was automatically scored as "Likely Residual LNAPL"
3. If neither dye test kit results nor BTEX/Naphthalene analytical results indicated the presence of LNAPL or if data was unavailable, the following scoring was used:

Staining: 0 - None, no evidence of LNAPL
1 - Minimal staining, weak evidence of LNAPL
2 - Staining or dark staining, strong evidence of LNAPL
Odor: 0 - None, no evidence of LNAPL
1 - Slight/very slight odor, weak evidence of LNAPL
2 - Odor, or strong/very strong odor, strong evidence of LNAPL
Dye Test: 0 - None
4 - LNAPL present
PID: 0 - <45 ppmv, no evidence of LNAPL
1 - between 45 and 450 ppmv, weak evidence of LNAPL
2 - > 450 ppmv, strong evidence of LNAPL
Benzene: 0 - less than 20 mg/kg, no evidence of LNAPL
1 - between 20 and 200 mg/kg, weak evidence of LNAPL
2 - > 200 mg/kg, strong evidence of LNAPL
TPH (JP-4) 0 - less than 25 mg/kg, no evidence of LNAPL
1 - between 25 and 250 mg/kg, weak evidence of LNAPL
2 - > 250 mg/kg, strong evidence of LNAPL

Interpretations were made on 1-foot vertical intervals. Where data for a given parameter was available less frequently, the score from the closest location above was carried down unless there was a technical basis to do otherwise (e.g., significant change in lithologic unit, maximum depth of historical water table)

The score from all of the factors were summed for each 1-foot interval. Summed values of 6 and greater were considered vertical intervals where current or historical LNAPL presence was likely.

B. Interpretation of LNAPL data to develop LNAPL volumes.

To interpret the extent of LNAPL, the scores for the individual 1-foot intervals were summed for 10-foot intervals. The extent of LNAPL was then contoured manually for each 10-foot interval. Two different interpretations of LNAPL extent were made with the manual contouring. The first interpretation focused on scores greater than 30 on recent data from the Pre-Design Investigation borings and well borings from remedial action implementation, additionally informed by areas of measured LNAPL in monitoring wells and with consideration of whether LNAPL presence is supported by dissolved phase concentrations. This second, more conservative interpretation considered scores greater than 20 for a 10-foot interval representative of LNAPL presence and considered both historical and Pre-Design Investigation locations. Contours were extended to include monitoring wells known to have observed LNAPL but lack additional evidence of LNAPL (e.g. boring logs not available). The individual 10-foot contours were entered into the TecPlot model. Figures in Appendix B represent the estimated extent of LNAPL under these two interpretations. The figures in Appendix B show the TTZ and EBR treatment zones relative to the LNAPL interpretation footprints for the CZ, UWBZ, and LSZ respectively.

The implementation of the SEE system at the site focused treatment on the TTZ for the CZ, UWBZ, and LSZ. The operator (TerraTherm) indicated that they expecte treatment to a distance of 10 meters beyond the boundary of the TTZ based on previous experience. The radius of influence of the perimeter extraction wells of the SEE system is expected to extend beyond both the boundary of the TTZ and the TIZ boundary. A distance of 10 meters (20 meters outside of each TTZ) was estimated for the extended radius of influence. Tecplot was utilized to estimate the volumes of NAPL within each of the contours. The following volumes were provided based on the TecPlot model.

	LNAPL Volume Interpretation			Conservative LNAPL Volume Interpretation		
	Volume within TTZ (cu ft)	Volume between TTZ and TIZ Contour (cu ft)	Volume between TIZ Contour and ROI Contour (cu ft)	Volume within TTZ (cu ft)	Volume between TTZ and TIZ Boundary (cu ft)	Volume between TIZ Contour and ROI Contour (cu ft)
CZ	256,000	66,250	15,750	478,750	119,500	57,500
UWBZ	1,834,500	618,750	446,500	2,696,500	793,750	647,750
ULPZ	608,625	209,175	174,975	665,500	226,625	232,875
LLPZ	1,074,450	63,300	0	1,178,625	169,725	10,500
LSZ	4,193,991	341,010	78,246	5,616,250	903,500	271,750

2 - Calculate pore space volume in each lithologic unit in the thermal treatment zone.

A porosity of 0.3 was used for all lithologic units to remain consistent with the SEE design

	LNAPL Volume Interpretation			Conservative LNAPL Volume Interpretation		
	Pore Space Within TTZ (cu ft)	Pore Space between TTZ and TIZ Contour (cu ft)	Pore Space between TIZ Contour and ROI Contour (cu ft)	Pore Space Within TTZ (cu ft)	Pore Space between TTZ and TIZ Contour (cu ft)	Pore Space between TIZ Contour and ROI Contour (cu ft)
CZ	76,800	19,875	4,725	143,625	35,850	17,250
UWBZ	550,350	185,625	133,950	808,950	238,125	194,325
ULPZ	182,588	62,753	52,493	199,650	67,988	69,863
LLPZ	322,335	18,990	0	353,588	50,918	3,150
LSZ	1,258,197	102,303	23,474	1,684,875	271,050	81,525

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3 - Estimate saturation percentage in each lithologic unit based on TPH analytical data from PDI and RA well installation and

	Grain Density (g/cc)	LNAPL Density (g/cc)	Average Observed Concentration	Calculated LNAPL Saturation	Literature Value LNAPL Saturation
CZ	2.65	0.7787	1,760	1.40%	1.00%
UWBZ	2.65	0.7787	4,919	3.91%	4.10%
LPZ	2.65	0.7787	3,565	2.83%	2.80%
LSZ	2.65	0.7787	3,047	2.42%	5.80%

4 - Calculate volume of residual LNAPL.

Residual Volume within TTZs - Base LNAPL Volume Interpretation

	TTZ Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	76,800	1.40%	1,073	1.00%	768
UWBZ	550,350	3.91%	21,497	4.10%	22,564
ULPZ	182,588	2.83%	5,169	2.80%	5,112
LLPZ	322,335	2.83%	9,125	2.80%	9,025
LSZ	1,258,197	2.42%	30,442	5.80%	72,975
Total	2,390,270		67,305		110,446

Residual Volume between TTZ and TIZ Contour - Base LNAPL Volume Interpretation

	Treatment Area Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	19,875	1.40%	278	1.00%	199
UWBZ	185,625	3.91%	7,250	4.10%	7,611
ULPZ	62,753	2.83%	1,776	2.80%	1,757
LLPZ	18,990	2.83%	538	2.80%	532
LSZ	102,303	2.42%	2,475	5.80%	5,934
Total	389,546		12,317		16,032

Residual Volume between TIZ Contour and ROI Contour - Base LNAPL Volume Interpretation

	Total Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	4,725	1.40%	66	1.00%	47
UWBZ	133,950	3.91%	5,232	4.10%	5,492
ULPZ	52,493	2.83%	1,486	2.80%	1,470
LLPZ	0	2.83%	0	2.80%	0
LSZ	23,474	2.42%	568	5.80%	1,361
Total	214,641		7,352		8,370

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Residual Volume within TTZs - Conservative LNAPL Volume Interpretation

	TTZ Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	143,625	1.40%	2,007	1.00%	1,436
UWBZ	808,950	3.91%	31,597	4.10%	33,167
ULPZ	199,650	2.83%	5,652	2.80%	5,590
LLPZ	353,588	2.83%	10,009	2.80%	9,900
LSZ	1,684,875	2.42%	40,765	5.80%	97,723
Total	3,190,688		90,031		147,817

Residual Volume between TTZ and TIZ Contour - Conservative LNAPL Volume Interpretation

	Treatment Area Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	35,850	1.40%	501	1.00%	359
UWBZ	238,125	3.91%	9,301	4.10%	9,763
ULPZ	67,988	2.83%	1,925	2.80%	1,904
LLPZ	50,918	2.83%	1,441	2.80%	1,426
LSZ	271,050	2.42%	6,558	5.80%	15,721
Total	663,930		19,726		29,172

Residual Volume between TIZ Contour and ROI Contour - Conservative LNAPL Volume Interpretation

	Total Pore Space (cu ft)	Calculated LNAPL Saturation	Calculated Volume of LNAPL (cu ft)	Literature Value LNAPL Saturation	Literature Volume of LNAPL (cu ft)
CZ	17,250	1.40%	241	1.00%	173
UWBZ	194,325	3.91%	7,590	4.10%	7,967
ULPZ	69,863	2.83%	1,978	2.80%	1,956
LLPZ	3,150	2.83%	89	2.80%	88
LSZ	81,525	2.42%	1,972	5.80%	4,728
Total	366,113		11,871		14,913

Total Residual Volume - LNAPL Volume Interpretation
Numbers taken from Pre-SEE LNAPL Volume Calcs

	Base		Conservative	
	Calculated Volume of LNAPL (cu ft)	Literature Volume of LNAPL (cu ft)	Calculated Volume of LNAPL (cu ft)	Literature Volume of LNAPL (cu ft)
CZ	1,438	1,029	2,855	2,043
UWBZ	37,773	39,649	55,057	57,792
LPZ	19,223	19,013	23,078	22,827
LSZ	34,082	81,702	53,553	128,377
Total	92,516	141,393	134,543	211,039

5 - Estimate the amount of LNAPL that has been removed by pre-SEE treatment and natural attenuation.
See FFS (AMEC, 2012) for basis/references.

	UWBZ (gallons)	LSZ (gallons)	Total (gallons)	
TEE Pilot	9,070	9,070	18,140	(assumed roughly equal in each zone)
Biodegradation	997	4,986	5,980	(100 % LSZ from 1969-1997, then 50/50)
Skimming/Bioslurping	0	10,564	10,564	(primarily removed from LSZ)
Total	10,067	24,620	34,684	

Note: Additional LNAPL mass has been removed from the CZ by the deep soil SVE system but has not been quantified specific to this zone and has not been included in the historical removal estimate.

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6 - Calculate the estimated range of post-SEE treatment remaining residual LNAPL.
Base LNAPL Interpretation

		TTZ Volume		TIZ Contour Volume		ROI Contour Volume		Untreated EBR Volume	
Vertical Zone	**NAPL Parameter**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**
Cobble Zone	cu ft	1,073	768	278	199	66	47	21	15
	gallons	8,028	5,745	2,078	1,487	494	353	157	112
	NAPL Removed	7,226	5,170	1,247	892	148	106	0	0
	Remaining NAPL (gallons)	803	574	831	595	346	247	157	112
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	602	431	540	387	190	136	78	56
Upper Water Bearing Zone	cu ft	21,497	22,564	7,250	7,611	5,232	5,492	3,794	3,982
	gallons	160,794	168,781	54,233	56,927	39,136	41,080	28,377	29,786
	NAPL Removed	144,715	152,910	32,540	34,156	11,741	12,324	0	0
	Remaining NAPL (gallons)	16,079	15,871	21,693	22,771	27,395	28,756	28,377	29,786
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	12,060	11,904	14,101	14,801	15,067	15,816	14,188	14,893
Upper Low Permeability Zone (All LPZ for Untreated EBR)	cu ft	5,169	5,112	1,776	1,757	1,486	1,470	1,129	1,117
	gallons	38,662	38,241	13,288	13,143	11,115	10,994	8,447	8,355
	NAPL Removed	11,599	11,472	0	0	0	0	0	0
	Remaining NAPL (gallons)	27,063	26,769	13,288	13,143	11,115	10,994	8,447	8,355
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	20,298	20,077	8,637	8,543	6,113	6,047	4,224	4,178
Lower Low Permeability Zone	cu ft	9,125	9,025	538	532	0	0	NA	NA
	gallons	68,253	67,510	4,021	3,977	0	0	NA	NA
	NAPL Removed	20,476	20,253	0	0	0	0	0	0
	Remaining NAPL (gallons)	47,777	47,257	4,021	3,977	0	0	NA	NA
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	NA	NA
	Lower Range (gallons)	35,833	35,443	2,614	2,585	0	0	NA	NA
Lower Saturated Zone	cu ft	30,442	72,975	2,475	5,934	568	1,361	597	1,431
	gallons	227,706	545,856	18,515	44,383	4,248	10,184	4,465	10,704
	NAPL Removed	204,936	493,733	11,109	26,630	1,274	3,055	0	0
	Remaining NAPL (gallons)	22,771	52,124	7,406	17,753	2,974	7,129	4,465	10,704
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	17,078	39,093	4,814	11,540	1,636	3,921	2,233	5,352
Cobble Zone and Upper Water Bearing Zone Thermal Treatment Zone	cu ft	27,739	28,445	9,305	9,566	6,784	7,009	4,379	5,114
	gallons	207,484	212,767	69,599	71,557	50,745	52,427	32,757	38,254
	NAPL Removed	163,539	169,552	33,787	35,048	11,889	12,430	0	0
	Remaining NAPL (gallons)	43,946	43,215	35,812	36,509	38,856	39,997	32,757	38,254
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	32,959	32,411	23,278	23,731	21,371	21,999	16,379	19,127

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		TTZ Volume		TIZ Contour Volume		ROI Contour Volume		Untreated EBR Volume	
Vertical Zone	NAPL Parameter	Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL	Calculated Volume of LNAPL	Literature Volume of LNAPL
Lower Saturated Zone Thermal Treatment Zone	cu ft	39,567	82,001	3,013	6,465	568	1,361	1,162	1,990
	gallons	295,959	613,366	22,536	48,360	4,248	10,184	8,689	14,882
	NAPL Removed	225,412	513,986	11,109	26,630	1,274	3,055	0	0
	Remaining NAPL (gallons)	70,548	99,381	11,427	21,731	2,974	7,129	8,689	14,882
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	52,911	74,535	7,427	14,125	1,636	3,921	4,344	7,441
Cobble Zone, Upper Water Bearing Zone, Low Permeability Zone, and Lower Saturated Zone	cu ft	67,305	110,446	12,317	16,032	7,352	8,370	5,541	6,545
	gallons	503,444	826,133	92,134	119,917	54,993	62,611	41,446	48,958
	NAPL Removed	388,950	683,538	44,895	61,678	13,163	15,485	0	0
	Remaining NAPL (gallons)	114,493	142,595	47,239	58,239	41,830	47,126	41,446	48,958
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	85,870	106,946	30,705	37,855	23,006	25,919	20,723	24,479

Conservative LNAPL Interpretation

		TTZ Volume		TIZ Contour Volume		ROI Contour Volume		Untreated EBR Volume	
	NAPL Parameter	Calculated Volume of LNAPL	Volume of LNAPL	Calculated Volume of	Volume of LNAPL	Volume of LNAPL	Volume of LNAPL	Volume of LNAPL	Volume of LNAPL
Cobble Zone	cu ft	2,007	1,436	501	359	241	15,658	106	-15,409
	gallons	15,014	10743	3,748	2,682	1,803	117,119	792	-115,262
	NAPL Removed	13,513	9,669	2,249	1,609	541	35,136	0	0
	Remaining NAPL (gallons)	1,501	1,074	1,499	1,073	1,262	81,983	792	-115,262
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	1,126	806	974	697	694	45,091	396	-57,631
Upper Water Bearing Zone	cu ft	31,597	33,167	9,301	9,763	7,590	7,967	6,568	6,894
	gallons	236,348	248,089	69,572	73,028	56,775	59,596	49,128	51,568
	NAPL Removed	212,714	223,280	41,743	43,817	17,033	17,879	0	0
	Remaining NAPL (gallons)	23,635	24,809	27,829	29,211	39,743	41,717	49,128	51,568
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	17,726	18,607	18,089	18,987	21,858	22,944	24,564	25,784
Upper Low Permeability Zone (All LPZ for Untreated EBR)	cu ft	5,652	5,590	1,925	1,904	1,486	1,470	2,565	2,537
	gallons	42,275	41,815	14,396	14,239	11,115	10,994	19,187	18,978
	NAPL Removed	12,682	12,544	0	0	0	0	0	0
	Remaining NAPL (gallons)	29,592	29,270	14,396	14,239	11,115	10,994	19,187	18,978
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	22,194	21,953	9,357	9,256	6,113	6,047	9,594	9,489
Lower Low Permeability Zone	cu ft	10,009	9,900	1,441	1,426	0	0	NA	NA
	gallons	74,870	74,055	10,782	10,664	0	0	NA	NA
	NAPL Removed	22,461	22,217	0	0	0	0	0	0
	Remaining NAPL (gallons)	52,409	51,839	10,782	10,664	0	0	NA	NA
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	NA	NA
	Lower Range (gallons)	39,307	38,879	7,008	6,932	0	0	NA	NA
Lower Saturated Zone	cu ft	40,765	97,723	6,558	15,721	568	1,361	5,662	13,572
	gallons	304,926	730,966	49,054	117,592	4,248	10,184	42,349	101,519
	NAPL Removed	274,433	657,870	29,433	70,555	1,274	3,055	0	0
	Remaining NAPL (gallons)	30,493	73,097	19,622	47,037	2,974	7,129	42,349	101,519
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	22,869	54,822	12,754	30,574	1,636	3,921	21,175	50,760
Cobble Zone and Upper Water Bearing Zone Thermal Treatment Zone	cu ft	39,256	40,193	11,727	12,025	9,317	25,095	7,956	-7,247
	gallons	293,637	300,647	87,716	89,949	69,694	187,709	59,513	-54,205
	NAPL Removed	238,909	245,493	43,992	45,426	17,574	53,014	0	0
	Remaining NAPL (gallons)	54,729	55,153	43,724	44,523	52,120	134,694	69,107	-44,715
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	41,047	41,365	28,421	28,940	28,666	74,082	34,554	-22,358

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		TTZ Volume		TIZ Contour Volume		ROI Contour Volume		Untreated EBR Volume	
Vertical Zone	**NAPL Parameter**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**	**Calculated Volume of LNAPL**	**Literature Volume of LNAPL**
Lower Saturated Zone Thermal Treatment Zone	cu ft	50,775	107,623	7,999	17,147	568	1,361	6,944	14,841
	gallons	379,796	805,022	59,836	128,256	4,248	10,184	51,943	111,008
	NAPL Removed	296,894	680,086	29,433	70,555	1,274	3,055	0	0
	Remaining NAPL (gallons)	82,902	124,935	30,403	57,701	2,974	7,129	51,943	111,008
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	62,176	93,702	19,762	37,506	1,636	3,921	25,971	55,504
Cobble Zone, Upper Water Bearing Zone, Low Permeability Zone, and Lower Saturated Zone	cu ft	90,031	147,817	19,726	29,172	9,885	26,456	14,901	7,594
	gallons	673,434	1,105,668	147,552	218,206	73,942	197,893	111,456	56,804
	NAPL Removed	535,803	925,579	73,424	115,981	18,848	56,070	0	0
	Remaining NAPL (gallons)	137,631	180,089	74,127	102,224	55,094	141,823	121,050	56,804
	Uncertainty Factor	75%	75%	65%	65%	55%	55%	50%	50%
	Lower Range (gallons)	103,223	135,067	48,183	66,446	30,302	78,003	60,525	28,402

Adjust calculated NAPL concentrations based on Post-SEE NAPL removal

Estimated total removal from SEE implementation based on TerraTherm weekly reports. Removal during final weeks estimated based on linear slope of removal line between

334,933 gallons

"Base - Calculated" remaining LNAPL concentrations are closest to actual conditions, so calibration ratio will be calculated with these values:

Post-SEE removal percentage:

Estimated by dividing actual data projections for LNAPL removal from base calculated total residual volume in the SEE treatment zone

71%

	LNAPL Removed (pounds)				BTEX + N Remaining (pounds)*				
	TTZ	Thermal Influence	ROI	Untreated EBR	TTZ	Thermal Influence	ROI	Untreated EBR	Total
				Base - Calculated					
Cobble Zone	37,688	7,225	696	0	99	490	226	94	909
Upper Water Bearing Zone	754,826	169,728	61,239	0	1,989	12,781	17,891	17,028	49,688
Low Permeability Zone	150,569	0	0	0	5,040	7,790	6,670	5,069	24,568
Lower Saturated Zone	1,068,937	57,943	6,648	0	2,816	4,363	1,942	2,679	11,801
Total	2,012,020	234,895	68,582	0	9,944	25,424	26,728	24,870	86,966

*fraction of BTEX+Naphthalene based on LNAPL analysis during SEE. Also assumes volatile fraction reductions of 90% in TTZ and 25% in thermal influence zone.

Summary of Pre-EBR Results (to be used for application of calibration ratio):

Includes assumption of removals laid out in Assumptions section, not the above removal based on actual data

	LNAPL Removed (gallons)				LNAPL Remaining (gallons)				
	TTZ	Terra	ROI	Untreated EBR	TTZ	TIZ	ROI	Untreated EBR	Total
				Base - Calculated					
Cobble Zone	7,226	1,247	148	0	803	831	346	157	2,136
Upper Water Bearing Zone	144,715	32,540	11,741	0	16,079	21,693	27,395	28,377	93,545
Low Permeability Zone	32,074	0	0	0	74,840	17,309	11,115	8,447	111,711
Upper Low Permeability	11,599	0	0	NC	27,063	13,288	11,115	NC	
Lower Low Permeability	20,476	0	0	NC	47,777	4,021	0	NC	
Lower Saturated Zone	204,936	11,109	1,274	0	22,771	7,406	2,974	4,465	37,615
Total	388,950	44,895	13,163	0	114,493	47,239	41,830	41,446	245,008

Calibration ratio (Total Removed by SEE Implementation/Total Estimated in Base - Calculated Case):

334,933/(388,950+44,895+13,163)= **0.75**

Pre-EBR Summary Results adjusted using calibration ratio:

	LNAPL Removed (gallons)				LNAPL Remaining (gallons)				
	TTZ	Terra	ROI	Untreated EBR	TTZ	TIZ	ROI	Untreated EBR	Total
				Adjusted for SEE Implementation Removal					
Cobble Zone	5,414	934	111	0	602	623	259	117	1,601
Upper Water Bearing Zone	108,431	24,382	8,797	0	12,048	16,254	20,526	21,262	70,091
Low Permeability Zone	24,033	0	0	0	56,076	12,969	8,328	6,329	83,703
Upper Low Permeability	8,691	0	0	NC	20,278	9,956	8,328	NC	
Lower Low Permeability Zone	15,342	0	0	NC	35,798	3,013	0	NC	
Lower Saturated Zone	153,554	8,324	955	0	17,062	5,549	2,228	3,346	28,184
Total	291,431	33,639	9,863	0	85,787	35,395	31,342	31,054	183,578

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Post-SEE LNAPL Removed and Pre-EBR BTEX+N Remaining using calibration ratio and converted into mass with volatilization reduction factor:

	LNAPL Removed (pounds)				BTEX + N Remaining (pounds)*				
	TTZ	Thermal Influence	ROI	Untreated EBR	TTZ	Thermal Influence	ROI	Untreated EBR	Total
Base - Calculated									
Cobble Zone	47,472	8,190	974	0	48	374	207	94	724
Upper Water Bearing Zone	950,775	213,788	77,137	0	965	9,763	16,439	17,028	44,194
Low Permeability Zone	210,729	0	0	0	4,491	7,790	6,670	5,069	24,019
Lower Saturated Zone	1,346,428	72,985	8,373	0	1,366	3,333	1,784	2,679	9,163
Total	2,555,404	294,963	86,483	0	6,870	21,260	25,100	24,870	78,100
Adjusted for SEE Implementation Removal									
Cobble Zone	35,570	6,137	729	0	36	280	155	71	542
Upper Water Bearing Zone	712,393	160,187	57,797	0	723	7,315	12,317	12,758	33,114
Low Permeability Zone	157,895	0	0	0	3,365	5,837	4,997	3,798	17,997
Lower Saturated Zone	1,008,847	54,686	6,274	0	1,024	2,497	1,337	2,008	6,866
Total	1,914,704	221,009	64,800	0	5,148	15,929	18,807	18,634	58,519

*fraction of BTEX+Naphthalene based on LNAPL analysis during SEE. Also assumes volatile fraction reductions of 90% in TTZ and 25% in thermal influence zone.

	Benzene Remaining (pounds)*				
	TTZ	Thermal Influence	ROI	Untreated EBR	Total
Base - Calculated					
Cobble Zone	2	15	8	4	29
Upper Water Bearing Zone	38	389	656	679	1,763
Low Permeability Zone	179	311	266	202	958
Lower Saturated Zone	54	133	71	107	365
Total	274	848	1,001	992	3,115
Adjusted for SEE Implementation Removal					
Cobble Zone	1	11	6	3	22
Upper Water Bearing Zone	29	292	491	509	1,321
Low Permeability Zone	134	233	199	151	718
Lower Saturated Zone	41	100	53	80	274
Total	205	635	750	743	0

Conclusion: Contaminant mass remaining was calculated using two methods. The first adjusts the expected performance of the SEE system based on projections of SEE operations data, as reported during TerraTherm Weekly Reports. This method reports a 71% removal of LNAPL using SEE treatment and a remaining BTEX+N mass of approximately 87,000 pounds. The second method adjusts the initial LNAPL mass using projections of SEE operations data, as reported during TerraTherm Weekly Reports. A calibration ratio, 0.75, was calculated using the "Base - Calculated" case determined during the Pre-EBR mass calculations and a projected final result of removal from the SEE implementation. This calibration ratio reduced remaining expected LNAPL results by 44%. Remaining BTEX+N at the site is estimated to be approximately 59,000 pounds.

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Purpose: Estimate Stoichiometric Requirements for Terminal Electron Acceptors using LNAPL estimates adjusted to actual SEE results.

Method: Multiply estimated LNAPL mass by stoichiometric requirements.

Assumptions: Ratio of Nutrient to NAPL (from US EPA 1998):

Sulfate 5 lb SO_4^{2-}/lb TPH

Oxygen 3.5 lb O_2/lb TPH

H_2O_2 Solution Concentration 32%

Constants and Inputs: 6.57 lbs of JP-4 per gallon

Molecular Weights (g/mol)

31.98 O_2

96.06 SO_4^{2-}

142.04 Na_2SO_4 anhydrous

246.47 $MgSO_4$ heptahydrate

34.01 H_2O_2

References: USEPA, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA/600/R-98/128, U.S. EPA, Washington, DC.

Calculations:

Considering all zones:

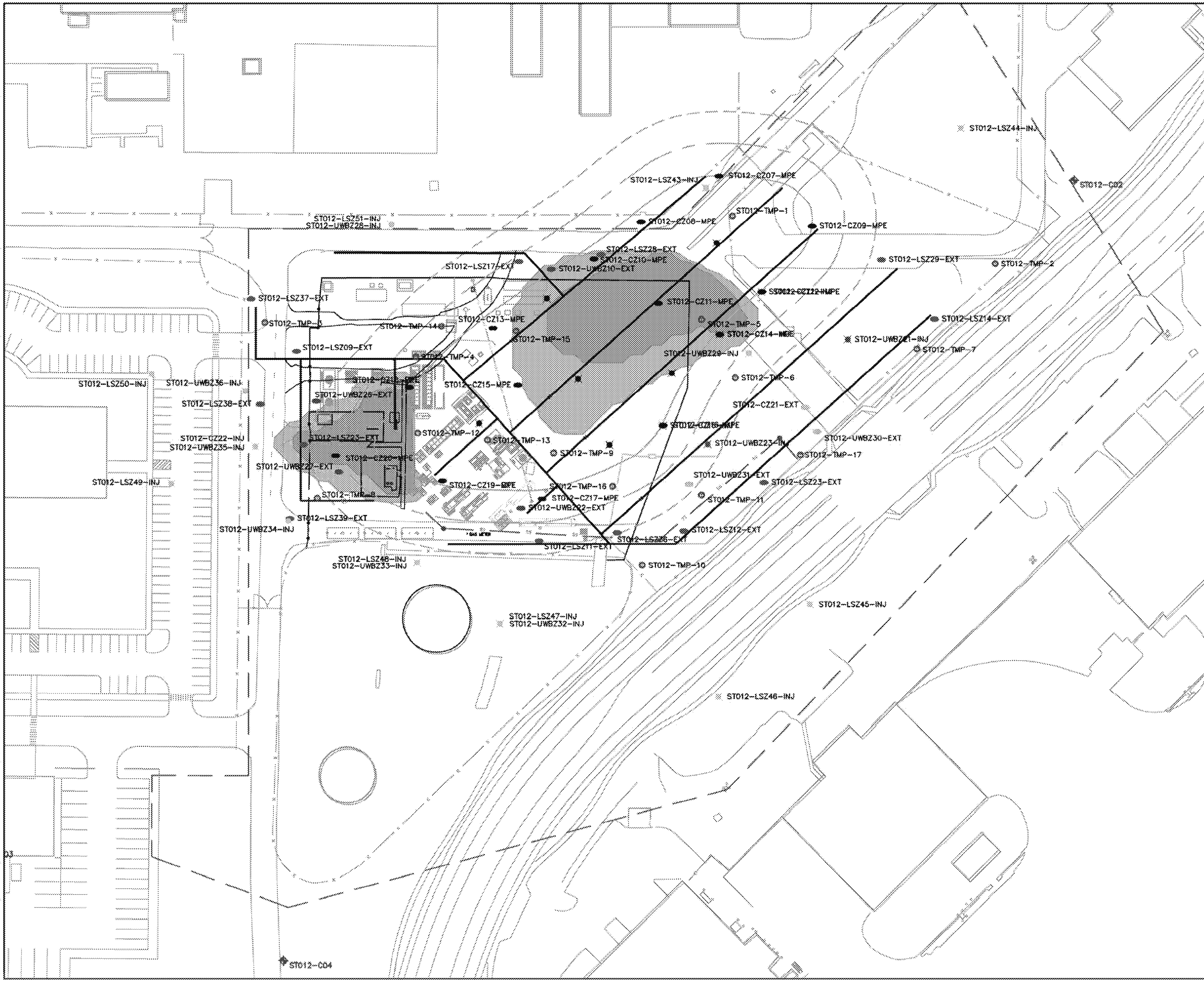
Base - Calculated	Remaining NAPL gallons	Remaining NAPL pounds	Required Nutrient Hydrogen Peroxide tons	Magnesium Sulfate tons	Sodium Sulfate tons
Cobble Zone	1,601	10,517	61	67	39
Upper Water Bearing Zone	70,091	460,496	2,678	2,954	1,702
Low Permeability Zone	83,703	549,925	3,198	3,527	2,033
Lower Saturated Zone	28,184	185,171	1,077	1,188	685
Total	183,578	1,206,110	7,015	7,737	4,459
Assumed Fraction Required to treat BTEX+N			30%	30%	30%
Required Amount			2,104	2,321	1,338

Considering CZ, UWBZ, and LSZ only (no LPZ)

Base - Calculated	Remaining NAPL gallons	Remaining NAPL pounds	Required Nutrient Hydrogen Peroxide tons	Magnesium Sulfate tons	Sodium Sulfate tons
Cobble Zone	1,601	10,517	61	67	39
Upper Water Bearing Zone	70,091	460,496	2,678	2,954	1,702
Lower Saturated Zone	28,184	185,171	1,077	1,188	685
Total	99,876	656,185	3,816	4,209	2,426
Assumed Fraction Required to treat BTEX+N			30%	30%	30%
Required Amount			1,145	1,263	728

APPENDIX B

MODELED LNAPL EXTENT FIGURES (REMAINING INTERVALS)



Legend

- PERIMETER MONITORING WELL
- SIW CZ = 6
- MPE CZ = 14
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- CZ RD/RAWP THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

CZ	COBBLE ZONE
LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

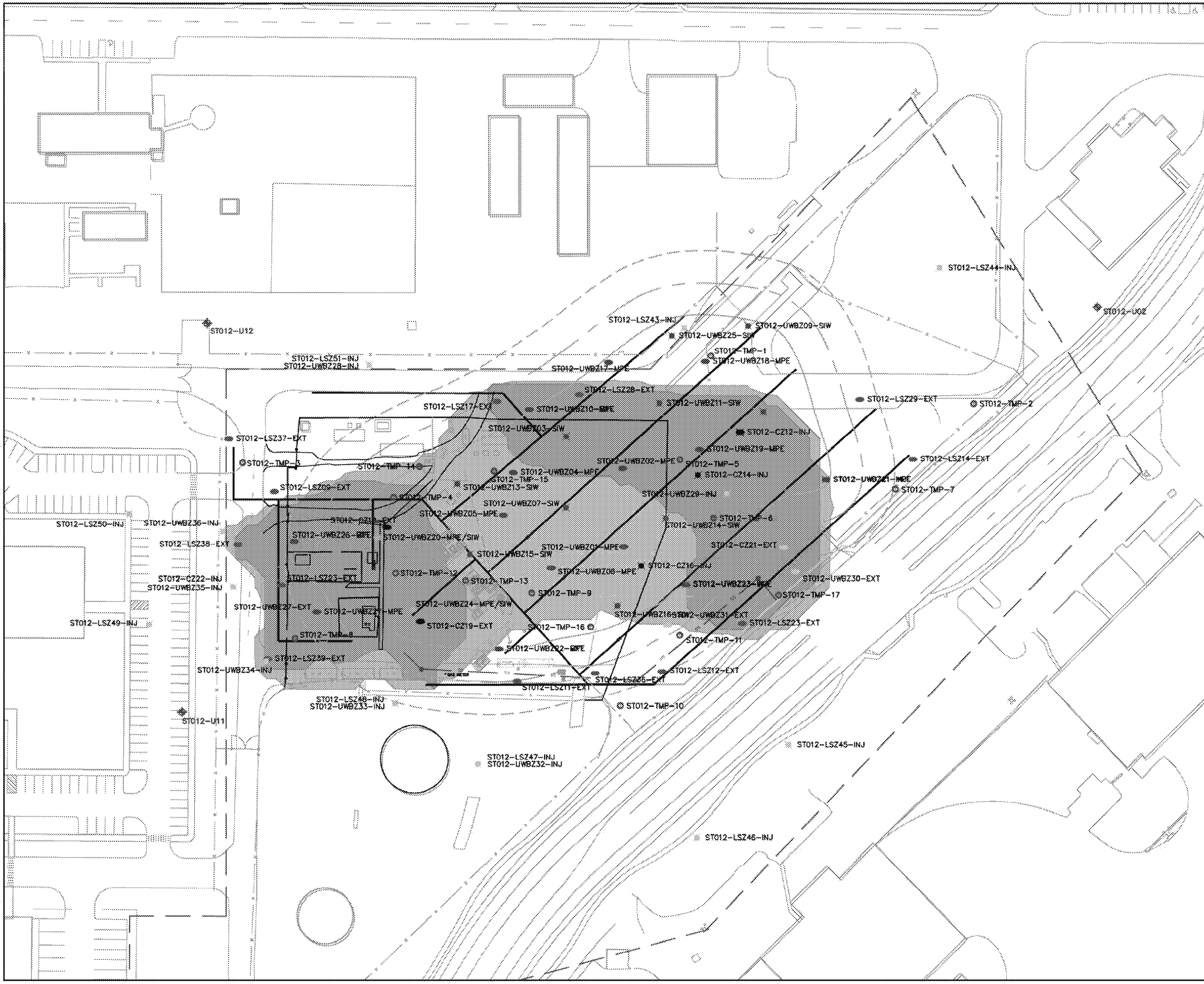
N

Draft, Addendum #2
Remedial Design/Remedial Action Work Plan
Site ST012 - Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent - CZ 150 FT BGS

FIGURE	
B-1	Job No.: 9101110001 PM: DS Date: 09/28/15 Scale: 1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW UWBZ = 10
- MPE UWBZ = 14
- DUAL PURPOSE UWBZ = 2
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- UWBZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT
UWBZ	UPPER WATER BEARING ZONE

0 50 100 Feet

N

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Remedial Design/Remedial Action Work Plan
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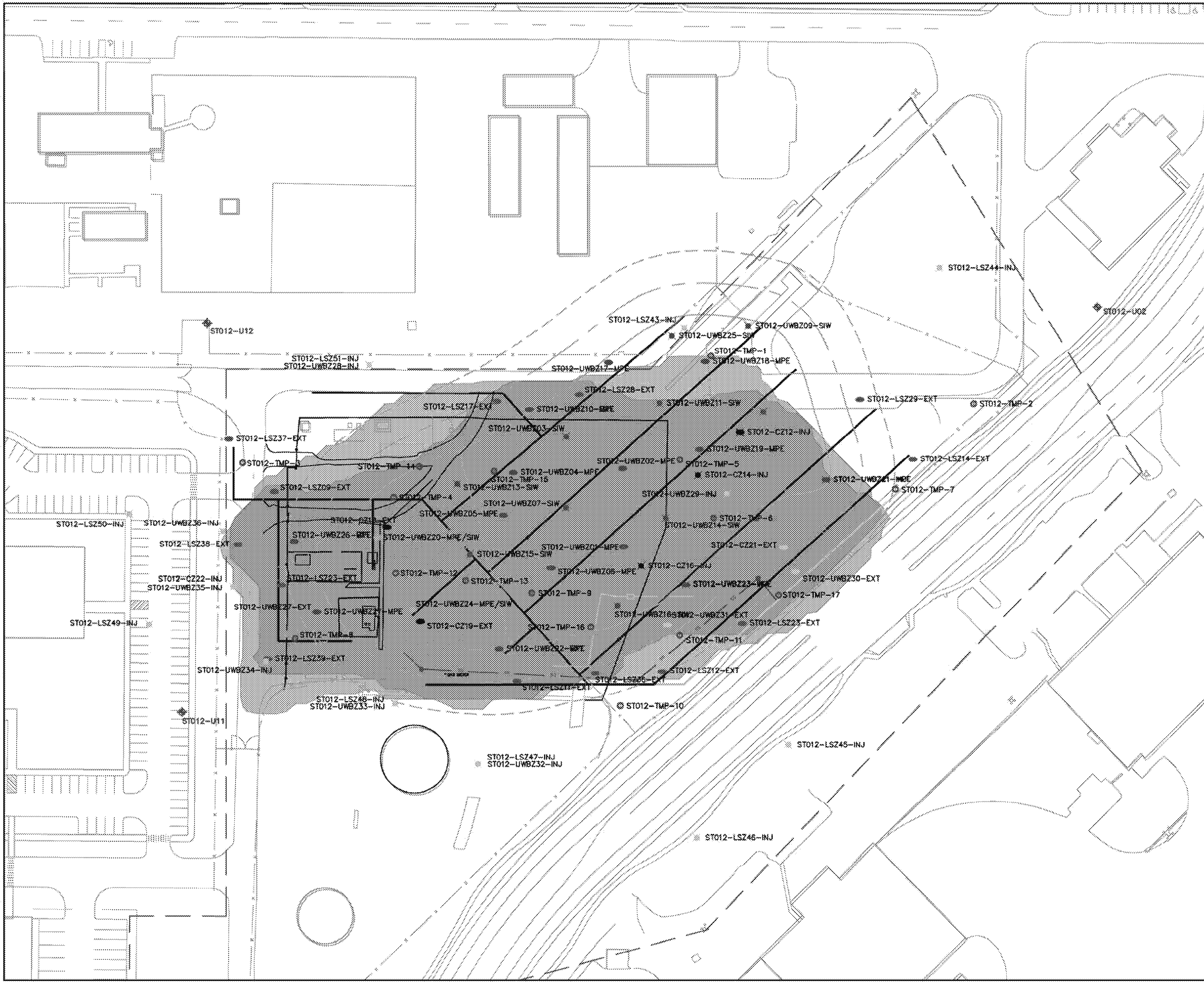
Mesa, Arizona

Modeled LNAPL Extent - UWBZ 170 FT BGS

FIGURE B-2	Job No.	9101110001
	PM:	DS
	Date:	09/28/15
	Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW UWBZ = 10
- MPE UWBZ = 14
- DUAL PURPOSE UWBZ = 2
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- UWBZ RD/RAWP THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT
UWBZ	UPPER WATER BEARING ZONE

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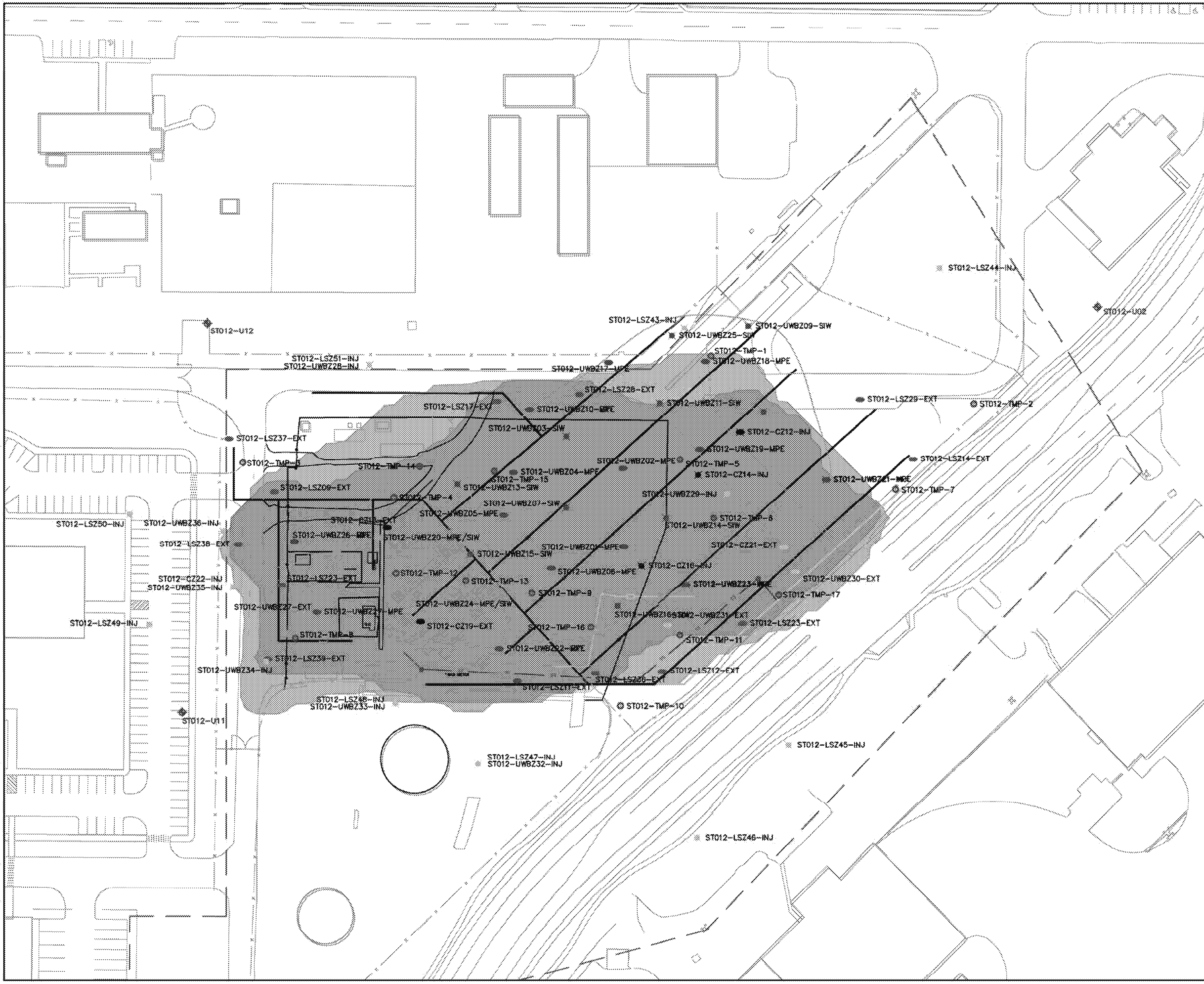
Remedial Design/Remedial Action Work Plan
Site ST012 - Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent - UWBZ 190 FT BGS

FIGURE B-3	
Job No.	9101110001
PM:	DS
Date:	09/28/15
Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW UWBZ = 10
- MPE UWBZ = 14
- DUAL PURPOSE UWBZ = 2
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- UWBZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

NOTE:
STEAM INJECTION WITHIN THE UWBZ IS EXPECTED TO IMPACT THE UPPER PORTION OF THE LPZ.

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LPZ	LOW PERMEABILITY ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT
UWBZ	UPPER WATER BEARING ZONE

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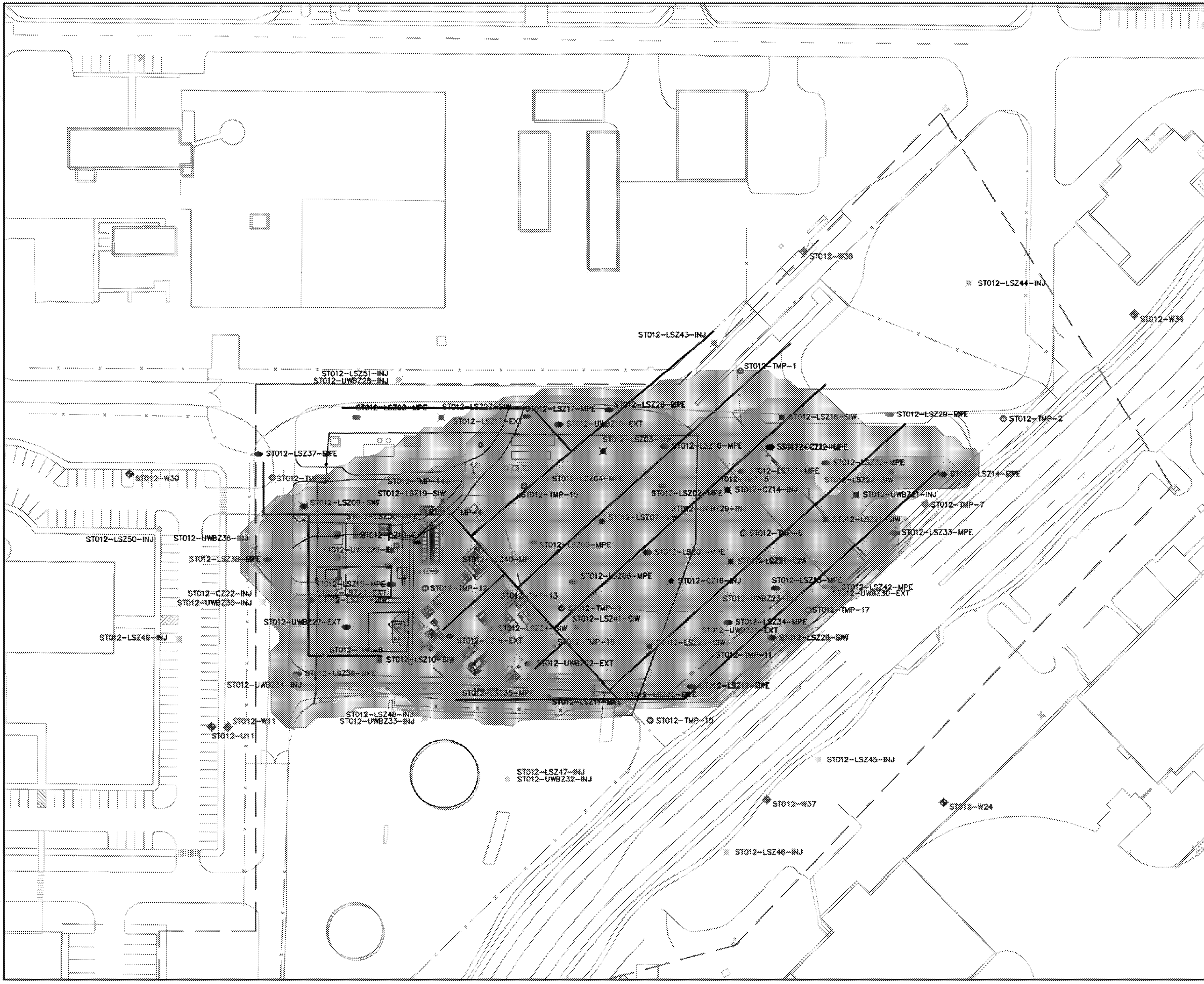
Modeled LNAPL Extent - LPZ 195 FT BGS

FIGURE		
B-4	Job No.	9101110001
	PM:	DS
	Date:	09/28/15
	Scale:	1"-100 Feet

amec foster wheeler



Legend

◈	PERIMETER MONITORING WELL
✱	SIW LSZ = 15
●	MPE LSZ = 27
◎	INDIVIDUAL TMP WITH THERMOCOUPLES = 17
	LSZ THERMAL TREATMENT ZONE
—W—	WATER LINE
—GAS—	NATURAL GAS LINE
—S—	SEWER LINE
	FENCE LINE
	ST012 BOUNDARY
	MODEL EXTENT OF RESIDUAL LNAPL-BASE
	MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

NOTE:
STEAM INJECTION WITHIN THE LSZ IS EXPECTED TO IMPACT THE LOWER PORTION OF THE LPZ.

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LPZ	LOW PERMEABILITY ZONE
LSZ	LOWER SATURATED ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100
Feet

N

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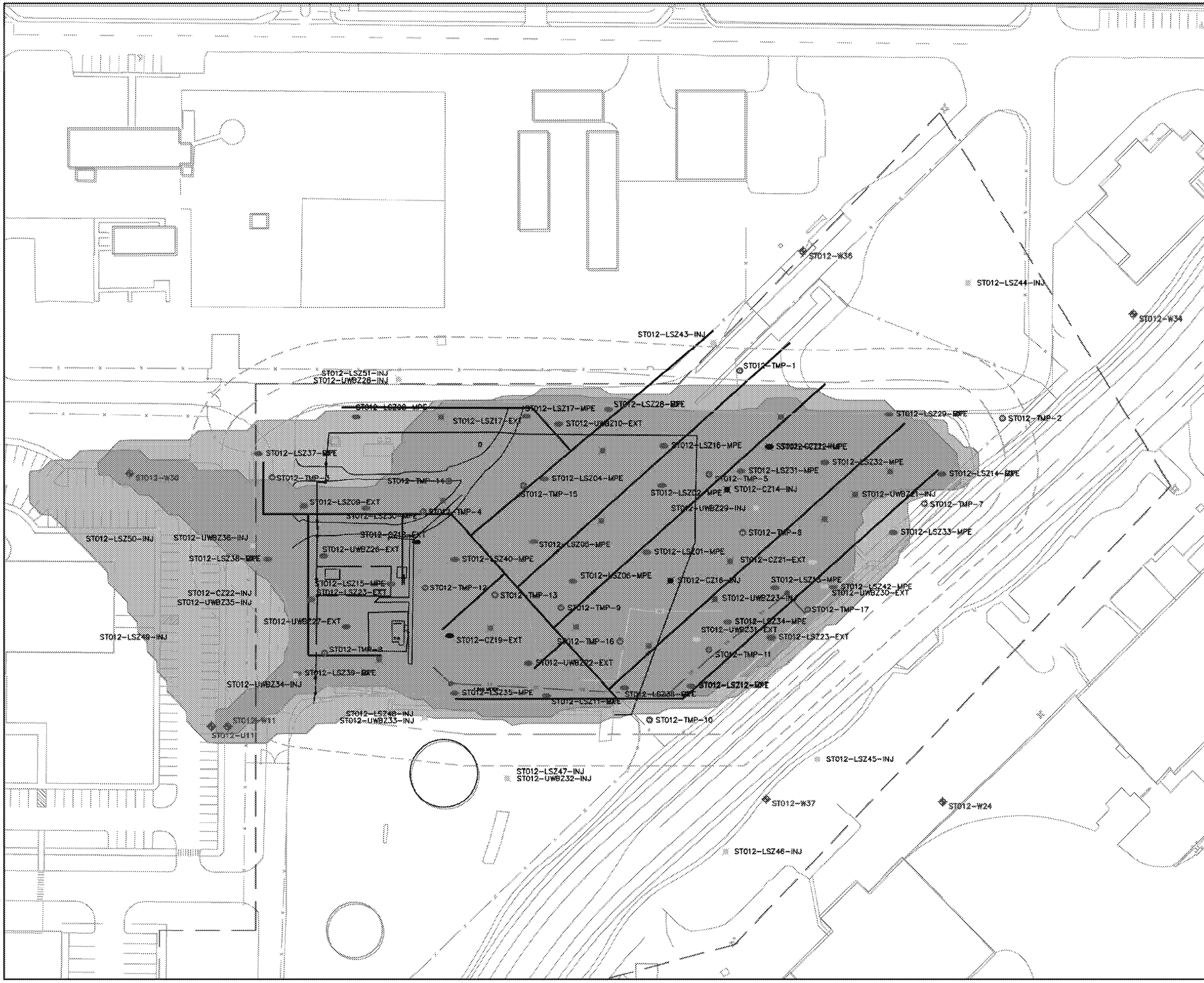
Modeled LNAPL Extent - LPZ 205 FT BGS

FIGURE	Job No.	9101110001
B-5	PM:	DS
	Date:	09/28/15
	Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW LSZ = 15
- MPE LSZ = 27
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- LSZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LSZ	LOWER SATURATED ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

N

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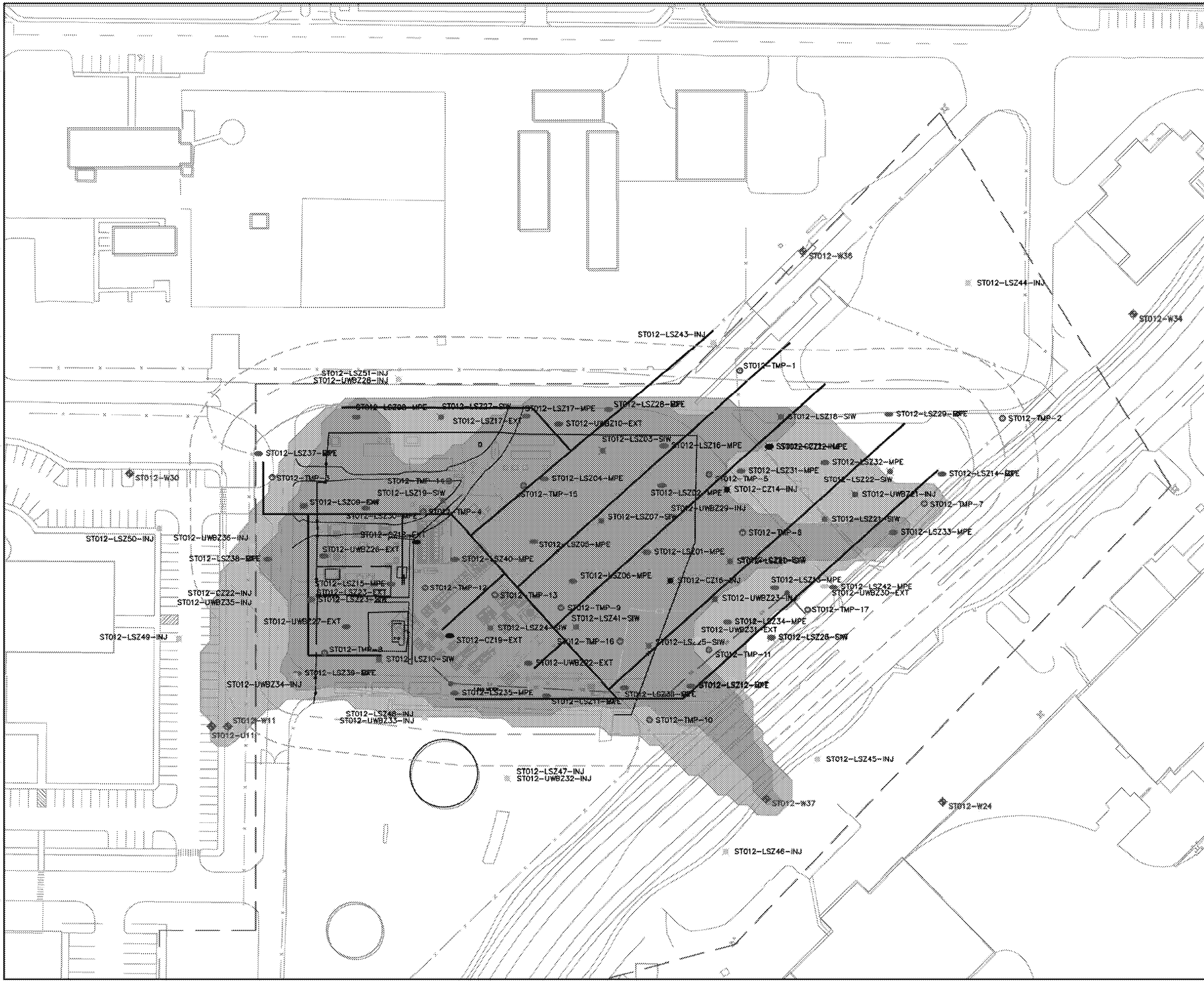
Modeled LNAPL Extent - LSZ 210 FT BGS

FIGURE		
B-6	Job No.	9101110001
	PM:	DS
	Date:	09/28/15
	Scale:	1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW LSZ = 15
- MPE LSZ = 27
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- LSZ THERMAL TREATMENT ZONE
- WATER LINE
- NATURAL GAS LINE
- SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LSZ	LOWER SATURATED ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

N

Draft, Addendum #2
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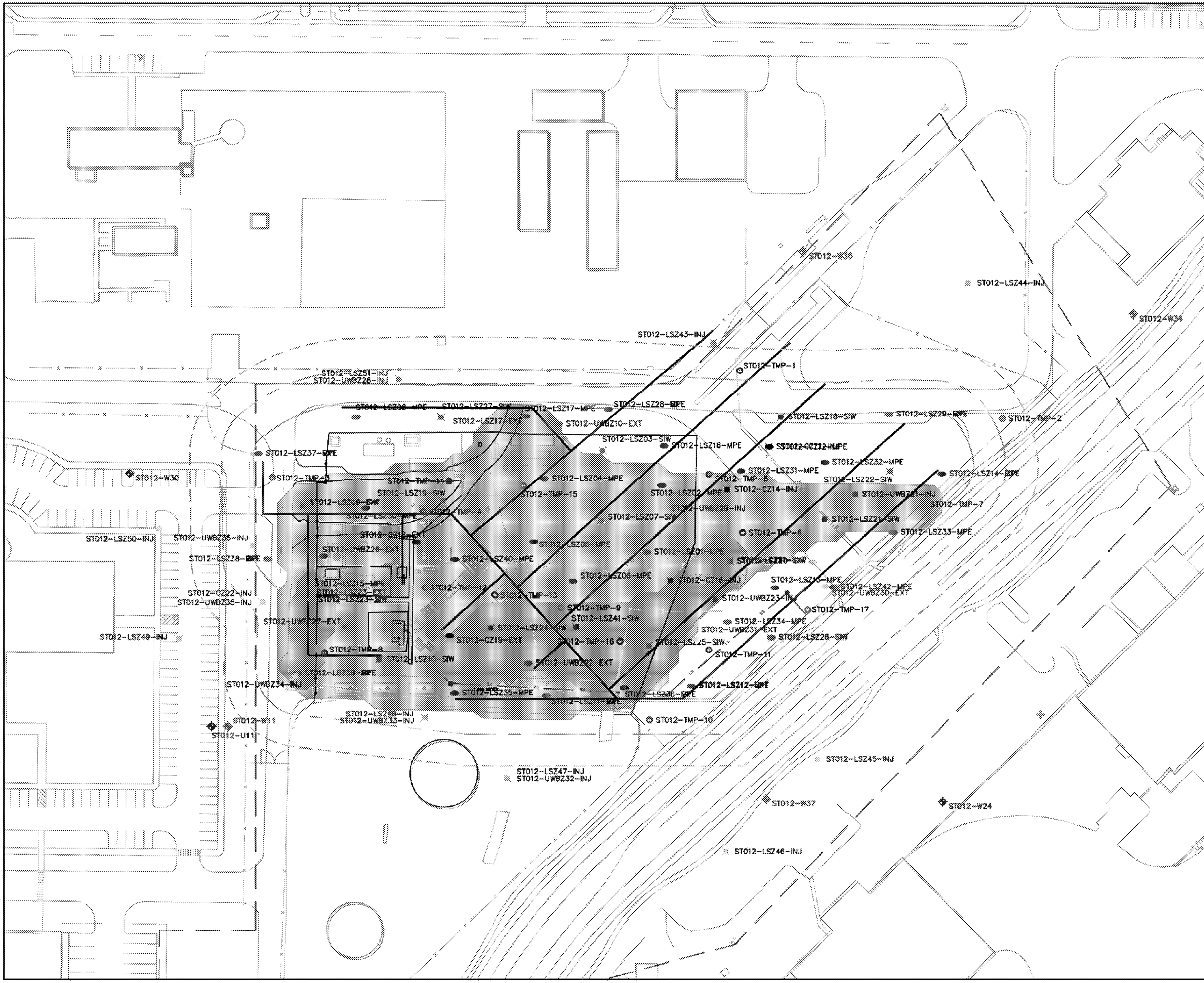
Site ST012 - Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent - LSZ 230 FT BGS

FIGURE	
B-7	Job No. 9101110001
	PM: DS
	Date: 09/28/15
	Scale: 1"-100 Feet

amec foster wheeler



Legend

- PERIMETER MONITORING WELL
- SIW LSZ = 15
- MPE LSZ = 27
- INDIVIDUAL TMP WITH THERMOCOUPLES = 17
- LSZ THERMAL TREATMENT ZONE
- W — WATER LINE
- GAS — NATURAL GAS LINE
- S — SEWER LINE
- FENCE LINE
- ST012 BOUNDARY
- THERMAL INFLUENCE ZONE, 60% REMOVAL
- ROI ZONE, 30% REMOVAL
- MODEL EXTENT OF RESIDUAL LNAPL-BASE
- MODEL EXTENT OF RESIDUAL LNAPL-CONSERVATIVE

Abbreviations

LNAPL	LIGHT NON-AQUEOUS PHASE LIQUID
LSZ	LOWER SATURATED ZONE
MPE	MULTI-PHASE EXTRACTION
SEE	STEAM ENHANCED EXTRACTION
SIW	STEAM INJECTION WELL
TMP	TEMPERATURE MONITORING POINT

0 50 100 Feet

N

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Remedial Design/Remedial Action Work Plan
Site ST012 - Former Williams Air Force Base
Mesa, Arizona

Modeled LNAPL Extent - LSZ 240 FT BGS

FIGURE B-8	Job No.	9101110001
	PM:	DS
	Date:	09/28/15
	Scale:	1"-100 Feet

amec foster wheeler

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APPENDIX C

ENHANCED BIOREMEDIATION FIELD TEST REPORT
(INCLUDED ON CD ONLY)